Journal
of
The Franklin Institute

EDITOR, HENRY BUTLER ALLEN, MET.E., D.Sc., Sc.D., D.ENG.

ASSISTANT EDITOR, NANCY S. GLENN, M.A.

Associate Editors:

WILDER D. BANCROFT, PH.D. — PAUL D. FOOTE, PH.D. — W. F. G. SWANN, D.SC.
CHARLES B. BAZZONI, PH.D. — C. E. K. MEES, D.SC. — HUGH S. TAYLOR, D.SC.
ARTHUR L. DAY, SC.D. — WILLIAM B. MELDRUM, PH.D. — A. F. ZAHM, PH.D.
R. EKSERGIAN, PH.D. — HENRY C. SHERMAN, SC.D. — JOHN ZELENY, PH.D.

Committee on Publications:

CHARLES B. BAZZONI, CHAIRMAN — RICHARD HOWSON — HIRAM S. LUKENS
G. H. CLAMER — CLARENCE L. JORDAN — WINTHROP R. WRIGHT
LIONEL F. LEVY

Vol. 249 **JUNE, 1950** **No. 6**

CONTENTS

Robert Fulton's First Steamboat ..... H. PHILIP SPRATT 435
Application of Near-Equilibrium Criteria During Adiabatic Flow to Representative Propellant Systems ..... S. S. PENNER 441
Concerning Meson Produced Secondary Electrons Emerging from Thin Foils ..... FRANK L. HEREFORD 449
Variations of Grid Contact Potential and Associated Grid Currents ..... HERBERT B. MICHAELSON 455
The Influence of the Temperature and the Period of Keeping upon the Biochemical Changes in the Common Fowl *Gallus Domesticus* (Part II) ..... JOSEPH SAMUEL HEPBURN 475
Notes from the National Bureau of Standards 491
The Franklin Institute
- Stated Monthly Meeting 495
- Journal of The Franklin Institute 495
- Committee on Science and the Arts 496
- The Franklin Institute Laboratories 496
- Membership 498
- Library 499
- Museum 501

Book Reviews 502
Book Notes 510
Notes from the Biochemical Research Foundation 513
Effects of Varying Oxygen Tension on Mortality of X-Rayed Mice ..... GEORGE LIMPEROS
Current Topics 474, 490, 515
Index to Volume 249 519

Published at
Prince and Lemon Streets, Lancaster, Penna., by
THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA
Benjamin Franklin Parkway at Twentieth St., Philadelphia 3, Penna.

DOMESTIC—EIGHT DOLLARS PER YEAR FOREIGN—NINE DOLLARS PER YEAR
(Foreign Postage Additional)
SINGLE CURRENT NUMBERS—ONE DOLLAR EACH
REPRINTS—FIFTY CENTS PER INDIVIDUAL INSTALLMENT

Indexes to the semi-annual volumes of the JOURNAL are published with the June and December numbers

Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 249 JUNE, 1950 No. 6

ROBERT FULTON'S FIRST STEAMBOAT

BY

H. PHILIP SPRATT[1]

There has recently been completed for the Marine Collections at the Science Museum, London, an operable model of the first experimental steamboat built, at Paris in 1803, for the famous American pioneer Robert Fulton (1765–1815) and successfully tried by him on the river Seine in the summer of that year. The model has been constructed to a scale of 1:27, from the plans drawn by Fulton himself (see Fig. 1), which are still preserved at the Conservatoire National des Arts et Métiers, in Paris. The model (see Figs. 2 and 3) is provided with hand drive, by means of which the public are enabled to set it in slow motion, so that the rather complicated movement of the side-lever mechanism can be clearly studied.

To appreciate the contribution made by Fulton in the development of steamboat propulsion, he may be considered as an inventor, adapter and shrewd business man, ready to use the results attained by others. It is an historic fact that he had made himself familiar with the discoveries in the use of steam up to the date of his successful experiment[2] and was thus able to avoid the errors that other inventors had made (1)., He is said to have had, while in Paris, full details of the pioneer work carried out at Philadelphia by his compatriot John Fitch (2). In 1802 he visited Scotland (3), and made a trial trip on the "Charlotte Dundas" of 1801, often described as the "first practical steamboat." Thus armed, and with adequate financial support in Paris, Fulton devoted himself in 1803 to the construction of his first experimental steamboat. He made no claim to the invention, but concentrated his attention on well-tried mechanisms and correct hull proportions.

[1] Deputy Keeper, Science Museum, London, England.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

The wooden hull was carvel-built, with a sharp chine, flat bottom and no external keel. The rounded stempost had a sharp abutment at the keelson. The vessel was rather bluff in the bows, with an extended parallel middle body and a short run-in aft. To compensate for the shallowness of hull, two longitudinal trusses were used to stiffen the structure; and these also served to support the vertical "steeple" guides for the piston crosshead. The square transom counter-stern carried a square-heeled rudder, which was steered with a simple hand tiller. There is no evidence that a sail was ever used; steam was relied upon as the sole propulsive force.

The steam cylinder used was one made by the French pioneer Jacques C. Périer, of Chaillot near Paris, from whom it was borrowed or hired by Fulton for the occasion (4). It was a vertical upright

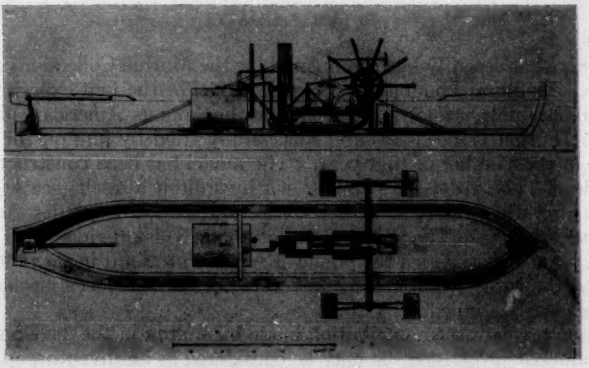


FIG. 1. Fulton's own plans for steamboat (1803).

double-acting cylinder 17.7 in. in diameter by 31.5 in. stroke, rated at 8 nominal h.p. Other parts of the machinery were constructed by Mr. Étienne Calla, of Paris. The crosshead at the upper end of the piston rod worked in vertical "steeple" guides (stiffened by the longitudinal trusses), from which the motion was taken down by return connecting-rods to a pair of triangular bell-crank side-levers with equal 3-ft. arms. From the upper points of these, the drive was taken by a horizontal connecting-rod to the paddle crankshaft. This was geared up, in 6:28 ratio, by toothed wheels to a high-speed shaft, placed lower down in the boat, which carried two heavy flywheels 5 ft. in diameter. The paddle-wheels were 12 ft. in diameter, each with ten fixed radial float boards 3 ft. long and 22 in. wide. It is probable that the paddle-wheels would have made about 15 rpm. for a speed of 4.5 mph.

For the boiler, Fulton had at first considered the use of the "flash" principle, in which the feed water is introduced into a red-hot chamber in sufficient quantities to produce steam as required for each stroke of the piston; a method later developed in France by Léon Serpollet. The description (5), consulted in the Bibliothèque Nationale at Paris, reads (translated) as follows:

> The steam chamber, placed in the middle of the fire-box, is a copper cylinder 4 in. diameter and the same in height. The piston cylinder is of brass, 2 in. diameter and about 24 in. long, and is screwed into the steam chamber. Just above this connection it is crossed by two inclined tubes, about 0.12 in. internal diameter. Water from the reservoir falls through one of these tubes into the steam chamber, which communicates with

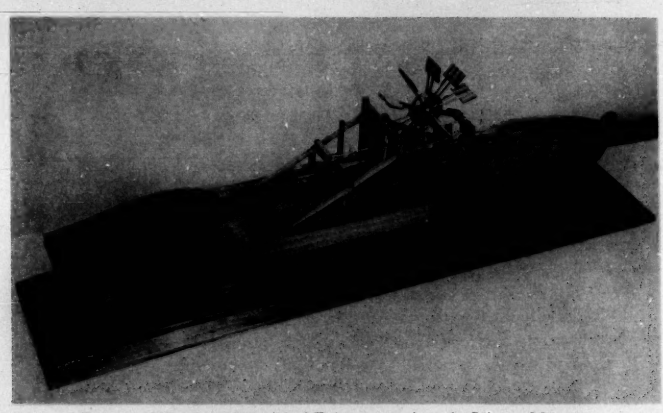


FIG. 2. Side view of model of Fulton steamboat in Science Museum.

> the atmosphere by the other tube. This double communication is controlled by cocks, which the piston rod of the motive cylinder opens and shuts at the proper intervals. Steam is formed in the red-hot chamber, and exerts its pressure on the underside of the piston. When at the top of its stroke, it opens the cock of the steam chamber to atmosphere; the piston descends under the action of a counterweight, and the steam pressure is renewed.

Fulton is said to have contemplated steam pressures of 450 psi.; but after some experiments with Mr. Calla, the copper of the steam chamber was found to deteriorate too rapidly, and the scheme was therefore abandoned.

In the end, Fulton is said (6) to have used an early form of water-tube boiler, invented by his friend Mr. Joel Barlow for steamboat use, and patented at Paris in 1793. This measured 7 ft. long, 5 ft. wide and

5 ft. high, and was constructed by Mr. Étienne Calla. It appears to have been wood-fired, and worked at a low steam pressure (perhaps not more than about 2 psi. above atmospheric). This boiler was later preserved in the Conservatoire National des Arts et Métiers, at Paris. Fulton also used a simple form of condenser, with vertical air pump 6 in. in diameter by 15 in. stroke, operated from an extension of the bell-cranks.

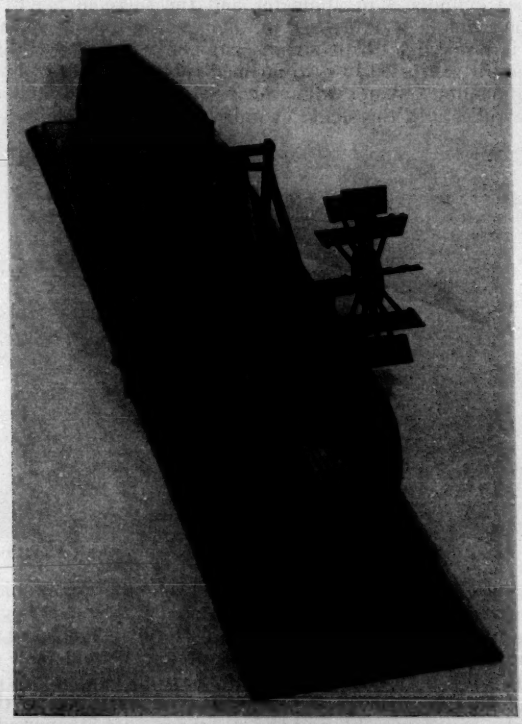


FIG. 3. Front view of model of Fulton steamboat.

After the boat had been completed and fitted, and was moored in the Seine ready for her steam trials, a violent storm arose. The hull proved unequal to the strain of the machinery in such circumstances; it broke in half, and the whole sank into the mud of the river. This was announced to Fulton while still in bed; he rushed at once to the spot (7), and labored all day in the river, without rest or food, to recover the

machinery. This imprudence left behind it a weakness which he felt to the end of his life. Undaunted by the mishap, however, he built another hull of somewhat heavier construction, into which the same machinery was refitted.

The steam trials of this boat were recorded at the time in a local newspaper (8); the account (translated) reads as follows:

> On the 21st Thermidor (the 9th August 1803) a trial was made of a new invention, the complete and brilliant success of which should have important consequences for the commerce and internal navigation of France. During the past two or three months there has been seen at the end of the quai Chaillot a boat of curious appearance, fitted with two large wheels mounted on an axle like a cart; while behind these wheels was a kind of large stove with a pipe, as if there was some kind of small fire-engine intended to operate the wheels of the boat. Several weeks ago some evil-minded persons threw the structure down. The builder, having repaired the damage, received the day before yesterday a most flattering reward for his labors and talent.
>
> At six o'clock in the evening, aided by three persons only, he put his boat in motion with two other boats in tow behind, and for an hour and a half he provided the curious with the strange spectacle of a boat moved by wheels like a cart, these wheels being fitted with paddles or flat oars, and turned by a fire-engine. Following it along the quay, the speed against the current of the Seine appeared to us about that of a hurried pedestrian; that is about 2400 toises (or 2.9 miles) per hour. Going downstream it was considerably more rapid. It mounted and descended four times, from the Bonshommes as far as the Pompe de Chaillot; it was manœuvred with facility, turned to the right and left, came to anchor, started again and passed in front of the Swimming School. . . . The author of this brilliant invention is Mr. Fulton, an American and a celebrated mechanician.

The boat is elsewhere stated to have attained speeds of 3.58 mph. (9) and 4.5 mph. (6).

Principal dimensions of the first hull (represented in the model) were as follows: displacement, about 25 tons; length over all, 66.5 ft.; length on water-line, 62.5 ft.; length of keel, 61 ft.; breadth of hull, 10.6 ft.; breadth over paddle-wheels, 17.5 ft.; depth of hull, 3.3 ft.; draught, 1.8 ft. Those of the second hull are said (10) to have been as follows: length, 74.6 ft.; breadth, 8.2 ft.; depth, 3.2 ft.

REFERENCES

(1) PURDY, T. C., "Robert Fulton and his steamboats." *Engineering Magazine*, New York, Vol. IX, No. 5, August 1895, pp. 868–877.

(2) FINCHAM, JOHN, *History of naval architecture*. London, 1851, p. 285.

(3) WOODCROFT, BENNET, *Sketch of the origin and progress of steam navigation*. London, 1848, pp. 64–65.

(4) ILLUSTRATION, *Histoire de la marine.* Paris, 1934, p. 323.
(5) HACHETTE, JEAN NICOLAS PIERRE, *Traité élémentaire des machines.* Quatrième édition, Paris, 1828, pp. 290–291.
(6) THURSTON, ROBERT H., *History of the growth of the steam-engine.* London, 1883, p. 255.
(7) SUPLEE, H. H., "Fulton in France." *Cassier's Magazine,* London, Vol. XXXII, No. 5, September 1907, pp. 405–419.
(8) *Journal des Débats,* Paris, 23 Thermidor (11 août) 1803.
(9) FINCHAM, JOHN, *History of naval architecture.* London, 1851, p. 286.
(10) DICKINSON, H. W., *Robert Fulton: engineer and artist.* London, 1913, p. 155.

APPLICATION OF NEAR-EQUILIBRIUM CRITERIA DURING ADIABATIC FLOW TO REPRESENTATIVE PROPELLANT SYSTEMS *

BY

S. S. PENNER [1]

ABSTRACT

Near-equilibrium criteria for chemical reactions during adiabatic flow through a nozzle are summarized. These criteria are then applied to two representative chemical systems. It is shown that the adiabatic expansion of the combustion products produced in the hydrogen-fluorine motor using the reactants in stoichiometric proportions should occur under conditions very closely approximating thermodynamic equilibrium. One of the near-equilibrium criteria is modified and used to demonstrate the departure from thermodynamic equilibrium for the decomposition of nitric oxide. This study of the equilibrium involving nitric oxide, nitrogen, and oxygen suggests the occurrence of practically frozen flow below a certain temperature, a result which is in agreement with the conclusions reached by a detailed numerical calculation.

I. INTRODUCTION

The occurrence of chemical reactions during adiabatic expansions through a nozzle is of interest because of the difference in rocket performance obtained for frozen and equilibrium flow (1, 2, 3).[2] In general, the adiabatic expansion through a nozzle would be expected to occur under conditions intermediate between equilibrium flow and constant-composition flow. The development of simple criteria for estimating the approach to equilibrium flow or to constant-composition flow is of value, since these criteria may obviate the necessity for a laborious analysis of the flow process of the type carried out previously for the decomposition of nitric oxide (1). Accordingly, the present discussion contains a summary of near-equilibrium criteria for the more important types of reactions which are likely to occur during adiabatic expansion through a rocket nozzle. Application of these near-equilibrium criteria to representative propellant systems is illustrated by detailed calculations.

II. KINETIC CRITERIA FOR DETERMINING THE OCCURRENCE OF NEAR EQUILIBRIUM IN FLOW PROCESSES

The derivation of a criterion for near equilibrium during flow processes was first given by Schaefer (3). A more rigorous development including proper allowance for concentration changes associated with

* This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under U. S. Army Ordnance Department Contract No. W-04-200-ORD-1482.

[1] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

changes in pressure and temperature has also been described (2). Since the development of near-equilibrium criteria for all types of chemical reactions is, in every detail, similar to the discussion given previously for the recombination of atoms, only the results of these considerations will be presented here.

A. Formation of Molecules from Free Atoms

The formation of molecules from free atoms as the result of triple collisions is given by the relation

$$M + A + B \rightleftarrows AB + M. \tag{1}$$

As has been shown previously (2), the general near-equilibrium criterion for the recombination of atoms to form molecules is

$$T' - T = \left(-\frac{dT}{dt}\right)\left(\frac{1}{k_f}\right) \times \left\{1 - \left[\left(\frac{Q}{RT} - 1\right)(\gamma - 1)\right]^{-1}\right\} \frac{1}{(M)[(A) + (B) + (1/K_c')]} \tag{2}$$

where

K_c' = equilibrium constant for reaction 1 at the temperature T' if the true temperature is T;
(A), (B), (AB) = concentrations of components A, B, AB, respectively;
$-dT/dt$ = rate of change of temperature with time during flow;
k_f = rate constant for forward reaction described in Eq. 1;
R = molar gas constant;
γ = ratio of specific heat at constant pressure to specific heat at constant volume;
Q = heat liberated when 1 mole of AB is formed at constant pressure according to Eq. 1.

The quantity K_c' is defined through the relation

$$K_c' = (AB)/(A)(B). \tag{3}$$

The near-equilibrium criterion described in Eq. 2 has been considered in detail previously (2). Some of the results of this analysis of molecule formation from free atoms will be employed later on in this discussion.

B. Deactivation of Excited Atoms or Molecules

For deactivation of the excited atom or molecule A^* to the normal atom or molecule A according to the unimolecular process

$$A^* \rightleftarrows A \tag{4}$$

it can be shown that

$$T' - T = \left(-\frac{dT}{dt}\right)\frac{1}{k_f}\frac{1}{1 + (1/K_c')} \tag{5}$$

where

$$K_c' = (A)/(A^*) \tag{6}$$

at the temperature T', and k_f now represents the rate constant for the forward reaction given in Eq. 4. For the formation of normal sodium atoms from excited sodium atoms, for example, k_f is given in terms of the sum of the Einstein coefficients of spontaneous and induced emission for a system in thermal equilibrium with its radiation (4).

C. Bimolecular Double-Decomposition Reactions

For the reaction

$$A + B \rightleftarrows C + D \tag{7}$$

it is found that

$$T' - T = \left(-\frac{dT}{dt}\right)\left(\frac{1}{k_f}\right)\frac{1}{(A) + (B) + [(C) + (D)]/K_c'} \tag{8}$$

where

$$K_c' = (C)(D)/(A)(B) \tag{9}$$

at the temperature T', and k_f is the rate constant for the forward reaction in Eq. 7.

For the double-decomposition reaction

$$2AB \rightleftarrows A_2 + B_2 \tag{10}$$

it is found similarly that

$$T' - T = \left(-\frac{dT}{dt}\right)\left(\frac{1}{k_f}\right)\frac{1}{(AB) + [(A_2) + (B_2)]/K_c'} \tag{11}$$

where

$$K_c' = (A_2)(B_2)/(AB)^2 \tag{12}$$

at the temperature T', and k_f is the rate constant for the decomposition of AB according to Eq. 10.

D. Other Reactions

It is, of course, possible to develop near-equilibrium criteria for chemical reactions other than those represented by Eqs. 1, 4, 7, and 10. The present discussion, however, will be confined to chemical reactions falling within the categories already described, and the need for further near-equilibrium criteria is therefore obviated. It should perhaps be emphasized that Eqs. 1, 4, 7, and 10 contain a description of the more important gas-phase reactions which will ordinarily be encountered during flow through a nozzle.

III. APPLICATION TO REPRESENTATIVE CHEMICAL REACTIONS

Equations 2, 5, 8, and 11 permit, in principle, a straightforward analysis on which a decision regarding the occurrence or nonoccurrence of near equilibrium during adiabatic expansions through a nozzle may

be based. Two specific illustrations of the use of these near-equilibrium criteria are described in this section.

A. The Hydrogen-Fluorine System

Performance calculations based on the usual assumption that thermodynamic equilibrium is attained in the combustion chamber show a specific impulse [3] of 352 seconds for the rocket motor using liquid hydrogen and liquid fluorine in stoichiometric proportions if near-equilibrium flow occurs, whereas the value of the specific impulse is only 321 seconds if no composition change occurs during flow.[4] The result of a kinetic analysis shows that it is probably possible to approach closely the high performance corresponding to equilibrium flow and that therefore the efficiency of experimental studies should be evaluated with respect to the higher specific impulse value.

Farber [4] has given the value for the chamber temperature as 4915° and for the exhaust temperature as 3640° K, provided equilibrium is maintained during expansion. The following equilibria must be considered for the hydrogen-fluorine system (5, 6, 7):

$$H + H + M \rightleftarrows H_2 + M \quad (13)$$

$$F + F + M \rightleftarrows F_2 + M \quad (14)$$

$$H + F + M \rightleftarrows HF + M \quad (15)$$

$$H + F_2 \rightleftarrows HF + F \quad (16)$$

$$H_2 + F \rightleftarrows HF + H \quad (17)$$

$$H_2 + F_2 \rightleftarrows 2HF \quad (18)$$

where M represents any third body.

Reactions 13 to 15 are of the type shown in Eq. 1, from which it follows that the near-equilibrium criterion given in Eq. 2 is applicable. Detailed calculations show that the temperature lags for reactions 13 and 14 are less than 25° K, even at the nozzle exit, if the rate constants for the recombination of hydrogen and fluorine atoms are similar, an assumption which is justified only by the lack of better data (2). The numerical values of the temperature lags are computed for temperature gradients $(-dT/dt)$ of 3×10^7 °K/sec., which are conservative values for large rocket motors (1, 2). It should be noted that a small temperature lag at the nozzle exit necessarily implies a smaller temperature lag

[3] The specific impulse is a measure of combustion efficiency and is proportional to the thrust on the rocket motor divided by the mass rate of discharge of combustion products through the rocket nozzle.

[4] Performance calculations for the hydrogen-fluorine system were made by M. Farber and are based on a value for the heat of dissociation of fluorine of 63.5 kcal. Since this value may be in error, the specific impulse values are only approximately correct. However, the large difference in specific impulse for the two types of flow will not be affected significantly by a change in the value of the heat of dissociation of fluorine.

during expansion through the nozzle and therefore assures the existence of near equilibrium during flow.

Detailed calculations for reaction 15 indicate an appreciable temperature lag ($T' - T \simeq 125°$ K) at the nozzle exit if the recombination of hydrogen and fluorine atoms could occur only as the result of reaction 15. Inspection of reactions 13 to 18 shows, however, that the same result can be achieved through the simultaneous occurrence of reactions 13 and 17 or of reactions 14 and 16, respectively. For a complex system of reactions of the type shown in Eqs. 13 to 18 it is apparent, therefore, that near-equilibrium flow can be achieved even if some of the reaction steps occur relatively slowly, provided there are alternate rapid reaction paths which lead to the same over-all result. Application of this principle will therefore lead to the conclusion that near equilibrium obtains with respect to reaction 15, provided reactions 13 and 17 or reactions 14 and 16 are rapid reactions. Similar remarks apply to reaction 18 which may be considered to result from the simultaneous occurrence of reactions 16 and 17.[5] For the purpose of the present analysis it therefore appears sufficient to restrict further discussion to reactions 16 and 17.

The chemical reactions represented by Eqs. 16 to 18 have been discussed by Eyring (5, 6, 7). A summary of the respective activation energies is reproduced in Table I (7). This table shows that the activation energy for either of the reactions shown in Eqs. 16 and 17 is of the order of 8 kcal or less. Since the temperatures are in excess of 3640° K during equilibrium flow, the exponential term $\exp(-E/RT)$ is greater than or equal to 0.33, and therefore the rate constants k_f are greater than or equal to $0.33B$ where B represents the effective frequency factor. Application of the collision theory of chemical reactions leads to a collision number of approximately 1×10^{12} (mol/liter)$^{-1}$ sec^{-1}. Use of the statistical theory of reaction rates (7) leads to a similar order of magnitude. Assuming a steric factor[6] of 0.1, it follows therefore that

$$k_f > 3 \times 10^{10} \text{ (mol/liter)}^{-1} \text{ sec}^{-1} \qquad (19)$$

throughout flow.

TABLE I.—*Activation Energies for the Hydrogen-Fluorine Reactions*

Reaction	Activation Energy (kcal) Observed	Calculated
$H + F_2 \rightleftarrows HF + F$	—	3.3 to 5.1
$H_2 + F \rightleftarrows HF + H$	8	6.3 to 10.6
$H_2 + F_2 \rightleftarrows 2HF$	>25	~50

[5] These qualitative conclusions can be expressed quantitatively as the result of a rigorous treatment of complex systems. A treatment of this type has been published elsewhere. [Cf. *J. Chem. Phys.*, Vol. 17, p. 841 (1949)].

[6] E. W. R. Steacie, *Atomic and Free Radical Reactions*, p. 35, New York, Reinhold Publishing Corp. (1946). According to Steacie, reactions of type 16 and 17 are generally characterized by steric factors of the order of 0.1.

The numerical value of $T' - T$ can now be computed from Eq. 8. For order of magnitude calculations $(-dT/dt)$ may again be set equal to 3×10^7 °K/sec.[7] The numerical values of $(A) + (B) + [(C) + (D)]/K_c'$ can be calculated from thermodynamic considerations. Using the value for k_f given in Eq. 19 and restricting calculation to conditions at the nozzle exit in order to obtain a probable maximum value for $T' - T$, it is found that

$$T' - T < 6° \text{ K} \tag{20}$$

for the reactions represented by Eqs. 16 and 17. Since the values of $T' - T$ are very small even at the nozzle exit, it may be concluded that thermodynamic equilibrium is probably maintained during flow for all practical purposes. This conclusion applies not only to reactions 16 and 17 but also to the entire system of reactions 13 to 18, since there seems to be an adequate number of rapid reaction paths to convert all of the reactants to the products which must be formed during near-equilibrium flow.

An analysis similar to that carried out here for the hydrogen-fluorine system using the reactants in stoichiometric proportions can readily be made for other compositions. The approach to thermodynamic equilibrium is strongly dependent upon the concentration of free atoms and upon the temperatures involved. Predictions of the behavior of non-stoichiometric mixture ratios of hydrogen and fluorine, without the more detailed consideration given here, are therefore usually not reliable.

B. The Nitric Oxide-Oxygen Equilibrium

The approach to thermodynamic equilibrium for the reaction

$$N_2 + O_2 \rightleftarrows 2NO \tag{21}$$

during isentropic expansion through a nozzle has been considered previously (1). A numerical analysis indicated that the equilibrium represented by Eq. 21 tended to freeze below about 2900° K for the conditions ordinarily encountered in a nitric acid-aniline propellant system when the temperature in the combustion chamber was 3000° K. An indication of wide departure from thermodynamic equilibrium can also be obtained, with the expenditure of considerably less work than is required

[7] A rough correction may be applied to the coefficient $-dT/dt$ calculated in reference 2 for the nitric acid-aniline motor before employing it for calculations on the hydrogen-fluorine motor. This correction involves use of the following relation:

$$\left(-\frac{dT}{dt}\right)_{H_2-F_2} = \left(-\frac{dT}{dt}\right)_{N-A} \times \frac{(T_c - T_e)_{H_2-F_2} \bar{v}_{H_2-F_2}}{(T_c - T_e)_{N-A} \bar{v}_{N-A}}$$

where the subscript H_2-F_2 refers to the hydrogen-fluorine motor, the subscript $N-A$ refers to the nitric acid-aniline motor, T_c is the chamber temperature, T_e is the exhaust temperature, $\bar{v}$ is an average linear velocity, and the assumption has been made that the nozzle dimensions are similar. The calculated results indicate that the order of magnitude of the coefficient $-dT/dt$ is the same for the two propellant combinations considered.

for a stepwise calculation, through judicious application of the appropriate near-equilibrium criterion.

The near-equilibrium criterion for the reaction represented by Eq. 21 is given by Eq. 11 with $(-dT/dt) \simeq 3 \times 10^7$ °K/sec. and $k_f \simeq RT \times 10^9 e^{-70,000/RT}$ (mol/liter)$^{-1}$ sec^{-1}. Introducing these numerical values into Eq. 11, it is found that

$$T' - T = 3 \times 10^{(30,395/RT)-2}\{p_{NO} + (p_{N_2} + p_{O_2})/K_c'\}^{-1} \qquad (22)$$

where use has been made of the perfect gas law, and p_{N_2}, p_{O_2}, and p_{NO} represent the partial pressures of nitrogen, oxygen, and nitric oxide, respectively. For temperatures less than 3000° K the value of K_c' is greater than about 70; the sum of the partial pressures of nitrogen and oxygen in a nitric acid-aniline rocket is less than about 5 atm, and p_{NO} is less than its initial value of 0.061 atm. (1). Hence

$$T' - T > 20 \times 10^{(30,395/RT)-2}. \qquad (23)$$

The numerical values of $T' - T$ as calculated from Eq. 23 are very large for temperatures less than about 2900° K for which a value of the order of 10^7 for $-dT/dt$ is a reasonable approximation. This result establishes the occurrence of significant departures from thermodynamic equilibrium, a conclusion which is borne out by more detailed calculations (1).

Equation 11 was derived by making the assumption that $T' - T$ is very small. The use of this relation for large values of $T' - T$ is therefore necessarily restricted to qualitative considerations. However, if accurate values are available for $-dT/dt$ near the chamber exit (1), then it is possible to employ Eq. 22 to determine the temperature below which effective freezing of the composition occurs. This calculation is not illustrated here because accurate values for $-dT/dt$ can be determined only at the expense of considerable effort. A quantitative analysis of the extent of composition changes during flow can be carried out with little more effort than an approximate application of the appropriate near-equilibrium criterion as soon as the temperature history of the gases is known accurately.

IV. CONCLUSION

The analysis of criteria for establishing near equilibrium or wide departures from thermodynamic equilibrium described in the present report should prove useful to the rocket engineer who is interested in obtaining, with a minimum of effort, a reasonable answer to the question of the nature of the flow process. In many cases a more detailed study of the extent of chemical reaction during flow than is afforded through the application of simple criteria will not be justified because of uncertainties in the rate constants for the chemical reactions under consideration.

REFERENCES

(1) S. S. PENNER AND D. ALTMAN, "Adiabatic Flow of Hydrogen Gas through a Rocket Nozzle With and Without Composition Change," JOURNAL FRANKLIN INST., Vol. 245, p. 421 (1948); D. ALTMAN AND S. S. PENNER, "Chemical Reactions During Adiabatic Flow Through a Rocket Nozzle," *J. Chem. Phys.*, Vol. 17, p. 56 (1949).

(2) S. S. PENNER, "Maintenance of Near-Equilibrium during Isentropic Expansion through a Nozzle," *J. Am. Chem. Soc.*, Vol. 71, p. 788 (1949).

(3) K. SCHAEFER, "On the Thermodynamics of Rocket Propulsion, I," available through Headquarters, Air Materiel Command, Wright-Patterson Air Force Base, Dayton, Ohio (February, 1947).

(4) L. PAULING AND E. B. WILSON, JR., "Introduction to Quantum Mechanics," New York, McGraw-Hill Book Co., Inc., 1935, p. 299.

(5) H. EYRING, "The Energy of Activation for Bimolecular Reactions Involving Hydrogen and Halogens According to the Quantum Mechanics," *J. Am. Chem. Soc.*, Vol. 53, p. 2537 (1931).

(6) H. EYRING AND L. S. KASSEL, "The Homogeneous Reaction Between Hydrogen and Fluorine," *Ibid.*, Vol. 55, p. 2796 (1933).

(7) S. GLASSTONE, K. J. LAIDLER, AND H. EYRING, "The Theory of Rate Processes," New York, McGraw-Hill Book Co., Inc., 1941, p. 236.

CONCERNING MESON PRODUCED SECONDARY ELECTRONS EMERGING FROM THIN FOILS *

BY

FRANK L. HEREFORD [1]

ABSTRACT

The probability is computed that a meson traversing a thin foil will produce at least one secondary electron of sufficient energy to emerge from the foil with the meson. Numerical results are presented for various meson momenta and foil thicknesses, and the bearing of these results upon certain low pressure Geiger-Mueller counter experiments is discussed.

It has been demonstrated (1)[2] that the specific primary ionization of a high energy particle can be determined by measurement of the counting efficiency of a Geiger-Mueller counter filled at a subnormal pressure. The counting efficiency is known to depend only upon the probability that at least one ion pair is initiated within the sensitive volume of the counter upon passage of an ionizing particle. In this connection low pressure counters have recently been utilized in certain cosmic ray experiments to discriminate among various types of particles as regards specific ionization (2, 3).

In order that such measurements can yield meaningful results it must be established that the discharge of the counter is caused by the effect of a single particle. The passage of a pair or a shower of particles would clearly be registered with a much higher efficiency.

Hence, considerations regarding the production in the counter walls of secondary electrons which enter the sensitive volume of the counter coincidentally with the original particle to be counted are important in interpretation of results. The extent to which the results are affected by such processes is dependent upon the counter pressure and the geometry of a given experimental arrangement; consequently, it varies from one experiment to another.

In most cosmic ray applications of G-M counter techniques the portion of the intensity which is lightly ionizing consists predominantly of mesons (the high energy electrons in the soft component are an exception, of course). Hence, in distinguishing more heavily ionizing particles by means of low pressure counters it is the "wall effect" for mesons which is important. It is to this instance that the following calculations

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission. The work was performed at Bartol Research Foundation of The Franklin Institute, Swarthmore, Pa.

[1] Now at Rouss Physical Laboratory, University of Virginia, Charlottesville, Va.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

are relevant; they are, however, applicable to any particle of unit charge for which the approximations employed are valid (electrons will be thus excluded).

It must be emphasized that the curves obtained by no means furnish corrections which can be applied to any counting efficiency data. In attempting to correct any set of data the geometry of the apparatus and the possible influence of scattering effects must be heavily weighed.

FORMULATION AND SOLUTION OF THE PROBLEM

In the following development we calculate the probability that a meson of a given energy traversing a small thickness of material ($x \ll$ radiation length) will produce at least one secondary electron which has sufficient energy to penetrate the remaining thickness of material and emerge with the incident meson.

The probability $\chi(E, Q)dQ$ for a meson of mass μ, charge ± 1, spin 0, and energy E, traversing a thickness dx (gm./cm.^{2}), to transfer an amount of energy between Q and $Q + dQ$ to a free electron as given by Bhabba (4) is

$$\chi(E, Q)dQ = \frac{2Cm}{\beta^2}\frac{dQ}{Q^2}\left(1 - \beta^2\frac{Q}{Q_M}\right). \tag{1}$$

In this expression m is the electronic mass, Q_M the maximum transferable energy, and C is a constant which in the units and notation of Rossi and Greisen (5) is

$$C = 0.15(Z/A). \tag{2}$$

The Rossi and Greisen notation will be employed throughout. Denoting by p the momentum of the incident meson, if $p \ll \mu^2/m \sim 2 \times 10^{10}$-$ev/c$, it can be shown (5) that

$$Q_M = 2m(p/\mu)^2 = 2m\frac{\beta^2}{1 - \beta^2}. \tag{3}$$

If further Q is small compared with both E and Q_M, the collision probability is independent of spin, justifying the use of the spin 0 collision probability of Eq. 1. These inequalities are satisfied in the problem to be considered.

In view of Eq. 1 the probability of a collision occurring in the interval x to $x + dx$ in which a meson of energy E produces a secondary electron of energy between Q and $Q + dQ$ *which penetrates the remaining wall thickness* is

$$\chi(E, Q)P(Q, x)dQdx$$

where $P(Q, x)$ is the probability that an electron of energy Q will penetrate x gm./cm.^{2}, *viz.*,

$$P(Q, x) = \begin{cases} 1, & \text{for} \quad x \leqq R(Q)\cos\theta(E, Q) \\ 0, & \text{for} \quad x > R(Q)\cos\theta(E, Q). \end{cases} \tag{4}$$

In this expression $R(Q)$ and $\theta(E, Q)$ are, respectively, the range and angle of emission of an electron of energy Q produced by a meson of energy E (Fig. 1). Hence the probability of a collision occurring in a

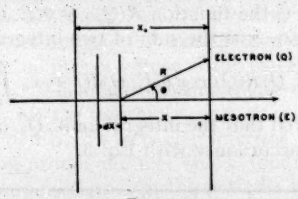


FIG. 1.

thickness x gm./cm.^{2} in which a meson of energy E produces a secondary electron of energy greater than η which penetrates the remaining wall thickness is

$$\nu_\eta(E) = \int_\eta^{Q_M} dQ \int_0^x \chi(E, Q)P(Q, x)dx.$$

This equation is valid if one takes η appreciably larger than the electronic binding energy in which case the electron can be considered free. In view of Eq. 4 the preceding expression may be written

$$\nu_\eta(E) = \int_\eta^{Q_M} \chi(E, Q)R(Q) \cos\theta(E, Q)dQ. \tag{5}$$

In order to evaluate this integral one must know the form of the functions $R(Q)$ and $\cos\theta(E, Q)$. The range function, $R(Q)$, can be quite closely approximated (6) in the range of electron energies which will be involved here by the expression

$$R(Q) = kQ^{\frac{1}{2}} \qquad (k = 4 \times 10^{-10} \text{ gm./(e.v.)}^{\frac{1}{2}} \text{ cm.}^2)$$

Although this gives the maximum range rather than the average range it is not a poor approximation, since from Fig. 1 one can see that scattering will effect a decrease in the distance traversed by an emerging secondary about as often as an increase. The function $\cos\theta(E, Q)$ can be obtained from the general theory of elastic collisions. In the coordinate system of the electron at rest, it follows from the conservation laws that

$$Q = 2m \frac{p^2 \cos^2\theta}{[m + (p^2 + \mu^2)^{\frac{1}{2}}]^2 - p^2 \cos^2\theta}.$$

For $p \ll \mu^2/m$ and $m \ll \mu$, this can be written

$$\cos\theta(E, Q) = \left\{ \frac{(p/\mu)^2 + 1}{(p/\mu)^2 + Q_M/Q} \right\}^{\frac{1}{2}}.$$

The functional form of the integrand in Eq. 5 is now determined.

In our particular case, however, there is a maximum value which the function $R(Q) \cos\theta(E, Q)$ can have, *viz.*, the thickness of the foil, x_0.

Let the value of Q corresponding to this thickness be denoted Q_0 such that

$$R(Q_0)\cos\theta(E, Q_0) = x_0. \qquad (6)$$

For higher values of Q the function $R(Q)\cos\theta(E, Q)$ will be a constant and one may write Eq. 5 as the sum of two integrals.

$$\nu_\eta(E) = \int_\eta^{Q_0(E)} \chi(E, Q)R(Q)\cos\theta(E, Q)dQ + x_0\int_{Q_0(E)}^{Q_M} \chi(E, Q)dQ. \qquad (7)$$

It must be remembered that the integral limit, Q_0, depends upon E for a given value of x_0 in accordance with Eq. 6.

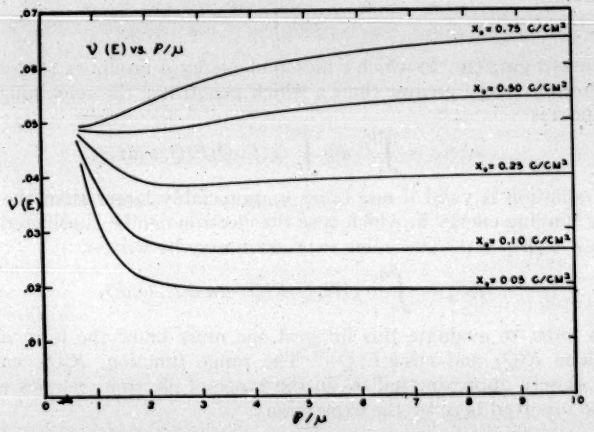


FIG. 2. The probability $\nu(E)$ *versus* meson momenta p/μ for various foil thicknesses.

Considering now the first of the integrals in Eq. 7 one finds upon substitution of the functions that it becomes

$$[\nu_\eta(E)]_{Q<Q_0} = \frac{2Cmk}{\beta^3}\int_\eta^{Q_0(E)} \left(1 - \beta^2\frac{Q}{Q_M}\right)(Q + 2m)^{-\frac{1}{2}}dQ.$$

Values of η less than 10^4 e.v. will not contribute appreciably to the quantity $\nu_\eta(E)$ for the range of thicknesses which we will consider. Hence, we will take $\eta = 10^4$ e.v. in which case $\eta \ll m$. Upon integration and rearrangement of terms this reduces to

$$[\nu_\eta(E)]_{Q<Q_0} = \frac{4Cmk}{\beta^3}\{[1 + (\tfrac{2}{3} - Q_0/6m)(1 - \beta^2)]\sqrt{2m + Q_0} - [1 + \tfrac{2}{3}(1 - \beta^2)]\sqrt{2m}\}. \qquad (8)$$

Integration of the second integral in Eq. 7 yields

$$[\nu_\eta(E)]_{Q>Q_0} = \frac{2Cm}{\beta^2}x_0\left\{\frac{1}{Q_0} - \frac{1}{Q_M} - \frac{\beta^2}{Q_M}\log\frac{Q_M}{Q_0}\right\}. \qquad (9)$$

Hence, with reference to Eqs. 8 and 9 it is seen that the final expression for $\nu_\gamma(E)$ is given by

$$\nu_\gamma(E) = [\nu_\gamma(E)]_{Q<Q_0} + [\nu_\gamma(E)]_{Q>Q_0}.$$

Numerical calculations are facilitated by plotting the function $R(Q) \times \cos\theta(E, Q)$ for various values of Q with p/μ as a parameter. It is then possible to determine proper values of the integral limit $Q_0(E)$ and compute values of $\nu(E)$: The most convenient curves indicating results show $\nu(E)$ *versus* p/μ with the foil thickness x_0 as a parameter (Fig. 2). Since the constant C of Eq. 2 which characterizes the material is the same for all elements of atomic number below about 60, the results are valid for all materials up to copper in the periodic table.

It is of interest to note the change in the shape of the ν *versus* x_0 curve (Fig. 3) with increasing values of p/μ; the physical significance of

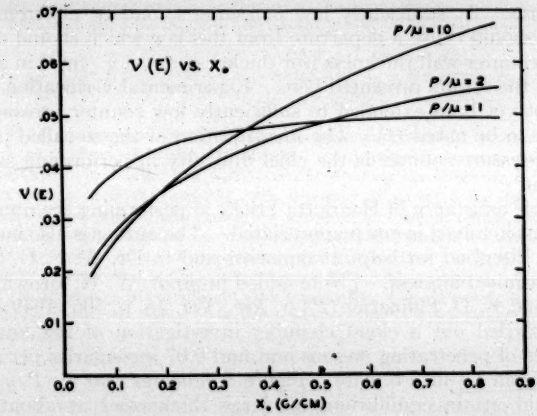


FIG. 3. The probability $\nu(E)$ *versus* foil thickness x_0 for various meson momenta.

the results is thereby evident. For small p/μ the average energy, Q, of the secondary electrons produced is small. Hence, only the last portion of the foil is effective in producing secondaries that can penetrate the remaining thickness. As a consequence, the curve for $p/\mu = 1$ is seen to level off above $x_0 \sim 0.4$ g./cm.^{2}. It is gratifying that this occurs at a thickness corresponding to the range of an electron of maximum transferable energy ($Q_M = 2m(p/\mu)^2 = 10^8$ e.v.).

For larger p/μ, however, the correspondingly higher secondary energies allow emergence from greater depths and the curve continues to rise with increasing thickness. For thicknesses approaching the radiation length in lead (5.9 g./cm.^{2}) the bremsstrahlung process, of course, will modify this argument (4). The fact that the curve for $p/\mu = 1$ lies above that for $p/\mu = 2$ or 10 for small x_0 is due to the in-

crease of ionization with decreasing momentum of the incident meson as exhibited by the well known ionization-momentum curve for charged particles. The minimum of this curve lies at $2 < p/\mu < 4$. The apparent convergence of the curves of Fig. 2 for small values of p/μ results from the fact that the increased number of secondaries produced have a small average energy. Hence, as regards production of secondaries *which can emerge from the foil* a thin foil is as effective as a thicker one.

The problem could be investigated experimentally in the following way. The counting efficiency of a G-M counter is known to depend upon the counter pressure as follows:

$$\text{Eff.} = 1 - e^{-lJP} \qquad (10)$$

where l and J are respectively the average path length and specific primary ionization of a counted particle and P is the counter pressure in atmospheres. At sufficiently low pressures secondary electrons from the walls should cause a departure from this law which should depend upon the counter wall thickness (for thicknesses < 1 g./cm.^{2}) in accordance with the results presented here. Experimental verification of Eq. 10 has not yet been extended to sufficiently low counter pressures for this effect to be noted (1). The identification of the so-called plateau of a low pressure counter is the chief difficulty in performing such an experiment.

The able assistance of Henrietta Fricke in performing the numerical calculations involved is much appreciated. The author is also indebted to Dr. L. Eisenbud for helpful comments and to Dr. W. F. G. Swann for his continued interest. [Note added in proof: W. W. Brown, A. S. McKay, and E. D. Palmatier (*Phys. Rev.*, Vol. 76, p. 506 (1949)) have recently carried out a cloud chamber investigation of the knock-on secondaries of penetrating mesons and find 0.07 secondaries per meson emerging from a $\frac{1}{2}$-in. Pb plate. Figure 3 indicates that for $P/\mu = 10$, $\nu(E)$ should attain equilibrium for large thicknesses at about 0.08. Choice of the constant C appropriate for Pb reduces this to about 0.065 in rough agreement with the above experimental value.]

REFERENCES

(1) W. E. DANFORTH AND W. E. RAMSEY, *Phys. Rev.*, Vol. 49, p. 854 (1936); M. G. E. COSYNS, *Bull. Acad. Belg.*, Vol. 5, p. 498 (1937).

(2) M. A. POMERANTZ AND F. L. HEREFORD, *Phys. Rev.*, Vol. 75, p. 1316A (1949). Low pressure counter experiments have also been performed by G. Bernardini and by the cosmic ray group at Applied Physics Laboratory, Johns Hopkins University in V-2 rockets.

(3) F. L. HEREFORD, *Ibid.*, Vol. 75, p. 923 (1949). An approximate calculation of the results given here was carried through for a particular case in this paper. The counter wall thickness employed in that calculation was incorrectly stated as 2.0 g./cm.^{2} instead of 0.6 g./cm.^{2}. The end result which was obtained there, however, is verified here as appropriate to that particular experiment.

(4) H. J. BHABBA, *Proc. Roy. Soc.*, Vol. 164, p. 257 (1938).

(5) B. ROSSI AND K. GREISEN, *Rev. Mod. Phys.*, Vol. 13, p. 240 (1941).

(6) L. E. GLENDENIN, *Nucleonics*, Vol. 2, p. 12 (1948).

VARIATIONS OF GRID CONTACT POTENTIAL AND ASSOCIATED GRID CURRENTS

BY

HERBERT B. MICHAELSON[1]

ABSTRACT

This survey is intended to serve as a guide to the literature on grid contact potentials and the associated grid currents. The difference of potential between grid and cathode of an electron tube is defined and separated into its component parts. The Volta potential, or "true contact potential," is shown to be the difference between work functions of grid and cathode. When the grid is negative the current in the external grid circuit consists of several small currents due to electron initial velocities, gas ions, interelectrode leakage, grid emission, and other miscellaneous factors. The grid voltage at which the resultant grid current is zero is a composite quantity

$$V_r = -(V_{gk} + V_z)$$

where V_{gk} is the grid-cathode Volta potential and V_z is the voltage equivalent of the various components of grid current. The quantity V_z is a spurious "contact potential."

The significance and use of the calculated correction potential ϵ for space-current equations is discussed briefly. In addition, the relationship between ϵ and tube characteristics is shown. The stabilization of dynamic characteristics of low-bias tubes having oxide cathodes has been described in recent literature. O'Neill, Champeix, and Gorelik have shown how a control grid can be coated with active material in order to stabilize $(\phi_k - \phi_g)$, and, in addition, Gorelik has also described a procedure for reducing grid emission from such a coated grid. Darbyshire suggests methods for controlling initial velocity currents by suitable processing.

The appendices list thermionic work functions for 44 pure metals, for contaminated metals, and for oxides. Also is listed the manner in which changing physical factors within the tube will tend to alter grid potential.

SYMBOLS

Since some of the symbols that appear in the literature are purely arbitrary, and since the accepted standards of usage have also changed in recent years, the following list has been adopted for this paper. Where an equation is cited from a reference, the symbols were changed to agree with this list in order to avoid confusion.

ϵ = calculated internal correction potential for use in space-current equations,

E_c = applied grid bias,

E_b = applied plate voltage,

E_f = applied filament voltage,

V_{gk} or $(\phi_k - \phi_g)$ = Volta potential (true contact potential) between control grid and cathode in temperature-limited operation,

[1] Sylvania Product Development Laboratories, Kew Gardens, N. Y.

V_g = Volta potential between grid and cathode in space-charge limited operation,
V_p = Peltier potential,
V_{pk} = Volta potential between grid and plate, temperature-limited operation,
V_r = retarding potential that brings grid current to zero (floating grid potential),
V_v = voltage equivalent of initial velocities at X_m, the virtual cathode,
V_x = spurious "contact potential" due to initial velocities, gas, leakage, etc.,
V_y = potential difference between monatomic film and base metal,
ϕ_g = thermionic work function of grid,
ϕ_k = thermionic work function of cathode,
I_s = saturation current,
I_c = total effective control grid current,
I_{vc} = initial velocity current, and
μ = amplification factor.

I. INTRODUCTION

The potential difference between control grid and cathode of a vacuum tube under zero-signal conditions is generally subject to change during the period of useful tube life. Such small variations are unimportant where the grid-bias operating point is relatively high, but in high-mu triodes, converters, and certain other receiving types where the bias is only one or two volts, these changes are significant. The effects of these variations of grid potential upon the dynamic characteristics of amplifier tubes have been reported by Bowie (1),[2] and methods of minimizing these variations in tubes having oxide cathodes have been described by O'Neill (2–4), Champeix (5), Gorelik (6), and Darbyshire (7).

The purpose of this review of the literature is to define true contact potential adequately and to show how it differs from the quantity[3] called "contact potential" that is generally measured in tests of production tubes; to identify the constituents of negative-grid currents; to show that the component parts of grid potential vary on life and thus alter tube characteristics; and to outline some of the methods that have been described in the literature for controlling these variations.

II. THE VOLTA POTENTIAL

Separate and distinct from considerations of thermionic emission and grid currents in a vacuum tube is a phenomenon known as the Volta

[2] The boldface numbers in parentheses refer to the references appended to this paper.

[3] This quantity, the value of E_c required to reduce I_c to zero, is the floating grid potential. For routine measurements some arbitrary value of I_c, such as one-tenth of a microampere, is usually selected because it is easier to determine than the actual zero point of I_c.

effect, or contact difference of potential. This Volt potential is best defined as a measurement of the work done in transferring a unit charge from any point just outside the surface of one metal to any point near the surface of the other metal, as illustrated in Fig. 1. When an electron

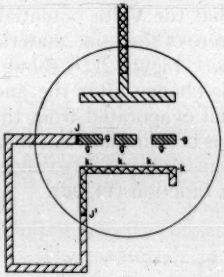


FIG. 1.

leaves the cathode it does work w_k, as it enters the grid metal it does work $-w_g$, and at junctions J and J' it does work $\pm w_j$. Then the Volta potential between grid surface and cathode surface is

$$V_{gk} = \frac{w_k - w_g \pm w_j}{e}$$

or, in terms of the voltage equivalents of work at the two surfaces and at the junctions J and J',

$$V_{gk} = \phi_k - \phi_g \pm V_p.$$

Since the Peltier potential V_p usually constitutes less than one per cent of V_{gk},

$$V_{gk} \cong \phi_k - \phi_g. \tag{1}$$

The sign of V_{gk} in tubes having oxide cathodes is usually such that it opposes the flow of electrons from cathode to grid. Experimental evidence of the relationship given by Eq. 1 has been reported by a number of investigators (**8–17**). According to Millman and Seely (**18**), the value $(\phi_k - \phi_g)$ is independent of any interconnecting metals, and thus only the cathode and grid surfaces are accounted for in Eq. 1. While this difference of potential is also unaffected by the area of the surfaces and by the distance between them, it does depend on the actual nature of the surfaces.

Since the quantity V_{gk} cannot be measured with a vacuum-tube voltmeter or any other direct-reading device, it must be determined by indirect methods. The graphic method of Schottky (**5, 12, 27, 28**) has been widely used for determining Volta potential in experimental diodes operated at low cathode temperatures so that space charge is negligible.

In the plot of E *versus* log I in Fig. 2(B), the straight portion of the curve at the left of the figure is extrapolated upward and the plateau of the saturation portion is likewise extended to the left. The point of intersection of the dotted lines represents the approximate value of the cathode-anode Volta potential.

Figure 2(A) shows that the Volta potential would be about zero if the cathode and anode were of the same material; in Fig. 2(B), $\phi_a > \phi_k$, and in Fig. 2(C), $\phi_a < \phi_k$. Figure 2(D) shows how the emission curve and the Volta potentials change after the anode surface has become contaminated by material evaporated from the cathode. Such a displacement of the curve has been utilized in calculating the work function of any given material that is purposely evaporated onto the surface of an anode of known work function (**14**, **30**).

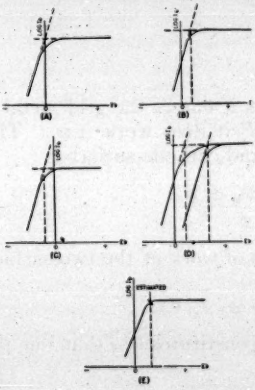


FIG. 2.

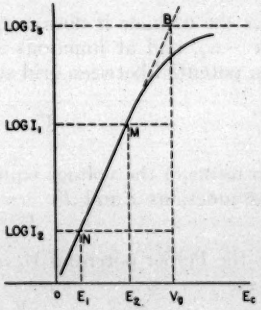


FIG. 3.

Another graphic method (**31**, **32**) of determining Volta potential is illustrated in Fig. 2(E). The potential ($\phi_r - \phi_a$) at which zero field emission will occur is found here by *estimating* the center of the knee of the curve.

The procedures shown in Fig. 2 have been used extensively for diode measurements. These graphic procedures have been adapted to the case of grid-cathode Volta potential by Champeix (**5**), who determined V_{gk} at low cathode temperatures and V_g at normal temperatures in triodes having oxide cathodes. The method used at 1000° K consisted of measuring I_s by pulse technique and then selecting two points M and N on the straight portion of the E *versus* log I curve in Fig. 3. From the law of similar triangles, the value V_g at abscissa B was

found by

$$V_0 = \frac{\log \frac{I_s}{I_1}(V_1 - V_2)}{\log \frac{I_1}{I_2} + V_1}. \qquad (3)$$

Champeix noted that because of the difficulty in obtaining a "true" value of I_s the graphic method of determining V_{ok} at 500 or 600° K is more accurate.

III. INITIAL ELECTRON VELOCITIES

While the Volta potential may be of such a polarity as to hinder the flow of electrons from the grid, a certain percentage of electrons emitted in a direction normal to the cathode will possess enough energy to overcome the retarding field and reach the grid. With no grid voltage actually applied, a small initial velocity current will thus tend to flow in the external grid circuit. The magnitude of this current will depend on the temperature of the cathode, the grid-cathode spacing, the work functions of grid and cathode, and other factors. Since the distribution of electron energies is approximately Maxwellian, as shown by several investigators (12, 27, 33, 34), initial velocity grid current increases exponentially with respect to the grid potential. In an oxide-coated emitter

average velocity = 0.15 electron volt
only 10^{-6} of i_k has initial velocity > 1.0 electron volt
only 10^{-9} of i_k has initial velocity > 1.5 electron volt.

Grid current due to initial velocities may be actually measured by means of a method described by Darbyshire (7). A microammeter in series with a one-megohm resistance was placed in the grid circuit of a vacuum triode. Since no plate voltage was applied, there was no grid-plate leakage and gas current in the grid circuit. With the exception of photo-electric grid currents, which are of the order of 0.001 microamperes, the current in the grid circuit was almost solely that of initial-velocity electrons. In a typical indirectly-heated vacuum triode, this current reading was about 1.0 microamperes, with a potential drop of 1 volt across the one-megohm resistor. Since the initial-velocity current is subject to change over the life of the tube and since a change in this current will affect the grid-cathode potential, the measurement technique described by Darbyshire can be useful in determining one of the causes of variations of grid potential.

In addition to the voltage drop produced across the grid resistor, initial velocities in a space-charge limited cathode current cause a negative dip V_m in the potential distribution between cathode and other electrode, as shown in Fig. 4. Langmuir (35) gave a complete mathematical solution for the field distribution between parallel planes in a diode.

In the case of potential distribution between a control grid and cathode, the Volta potential V_g is quite important. Figure 4(*B*) shows how in space-charge limited operation the effective potential between grid and cathode, *exclusive of applied grid voltage*,[4]

$$V_g \cong (\phi_k - \phi_g) - V_m. \tag{4}$$

At normal operating temperatures of an oxide cathode, V_m is usually greater than $(\phi_k - \phi_g)$. In some tubes, however, V_m is smaller, in which case no initial velocity current can flow in the grid circuit.

IV. NEGATIVE GRID CURRENTS

The physical factors which cause negative grid currents have been discussed by Metcalf and Thompson (36), Nielsen (37), Gould (38), and

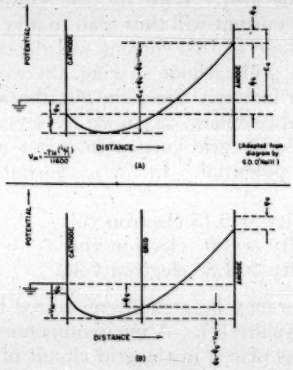


FIG. 4.

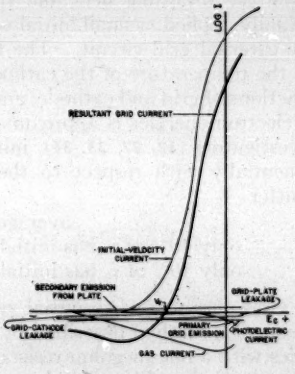


FIG. 5.

others. These components of negative grid current are listed here in approximate order of importance:

1. Ions of residual gas,
2. Leakage current over mica and other insulating supports in mount, stem, and base,
3. Primary grid emission due to heating of grid by cathode, and secondary emission due to bombardment by positive ions,
4. Photoelectrons emitted by grid under action of light from filament, external light, and soft X-rays produced by normal anode current, and
5. Ions emitted from the cathode.

All five of these components are no doubt subject to change during the life of the tube, and any such alteration will not only change the

[4] Applied grid voltage in this case includes any bias developed across a grid resistor.

shape of the resultant grid current curve shown in Fig. 5, but will also tend to shift the point V_r of zero current. Hypothetical curves of composite grid current, similar to that in Fig. 5, have appeared in the recent literature (39).

The floating-grid potential V_r is thus a composite value, rather than a measurement of the true contact potential and

$$V_r = -(V_{gk} + V_x) \tag{5}$$

where V_x is a *spurious* contact potential due to initial velocities, gas, leakage, and other miscellaneous effects.

V. THE CORRECTION POTENTIAL ϵ

Van der Bijl (41), Chaffee (29), Bowie (1), Terman (43), Reich (44), and others have defined the correction potential as the quantity which must be added to a space-current equation to account for the effects of initial velocity current and the contact difference of potential between cathode and other elements. In an empirical equation for triode plate current (1, 41, 45)

$$I_b = C\left(\frac{E_b}{\mu} + E_c + E\right)^n \tag{6}$$

C is a constant depending on tube dimensions and n is usually equal to about $\frac{3}{2}$ for unipotential cathodes. The exact value of n varies from about 1.2 to 2.5,* depending upon cathode emission, grid and plate voltages, and other factors. The correction potential ϵ and n are both empirical values.

While ϵ is approximately equal to the floating grid potential V_r, the exact value of ϵ cannot be measured directly. Bowie has defined ϵ in terms of measured tube characteristics by

$$\epsilon = -\frac{E_b}{\mu} - E_c + \frac{nI}{g_m} \tag{7}$$

where E_b is applied plate voltage, E_c is applied grid voltage, and n is usually $\frac{3}{2}$. Since the quantity ϵ is a function of tube ratings and characteristics, it can be readily seen that ϵ is affected by structural variables in the tube. Equation 7 is accurate for high- and medium-mu triodes.

O'Neill (4) has derived another expression for ϵ which may be used for both high- and low-mu triodes:

$$\epsilon = \frac{3\mu i}{2g_m(\mu + 1)} - \frac{\mu E_c + E_b}{(\mu + 1)} \tag{8}$$

---

* $n \cong 5/2$ for $\left\{\frac{E_b}{\mu} + E_c\right\} < E_f$ in filamentary types.

$n \cong 2$ for space-charge limited triode.

$n \cong 3/2$ for diode connection.

where E_c and E_b are applied grid and plate voltages, respectively, and i is space-charge-limited plate current. Calculations of ϵ can be useful to the design engineer in standardizing characteristics of a given tube type (4). If a tube is to have the characteristics g_m, μ, and i at specified grid and plate voltages, two of these characteristics may be selected, and the third will then have to fit all the other variables in (7) or (8) if the tube is to be rated properly.

Since in a triode the quantity ϵ is a lumped correction factor that accounts for all internally-generated voltages, it follows that

$$\epsilon \cong V_{gk} + \frac{V_{pk}}{\mu} - V_m + V_\tau \tag{9}$$

where

V_{gk} = the grid-cathode Volta potential,
V_{pk} = the plate-cathode Volta potential,
V_m = the minimum potential in the cathode-plate field distribution,
μ = the amplification factor, and
V_τ = the voltage equivalent of initial-velocity electrons at the minimum potential.

From Eq. 9 it is clear that the work function of the grid affects ϵ (and plate current) μ times more than does the work function of the plate.

VI. CHANGES IN ϵ DURING TUBE LIFE

The life characteristics of any high-mu tube are influenced by changes in ϵ. These alterations in ϵ are *caused* by the terms in the right-hand side of Eq. 9; alterations of ϵ *affect* g_m and plate current in Eqs. 7 and 8 when applied voltages and μ are constant.

As tube life progresses the most important changes in correction potential are probably due to a decrease in ϕ_g as the grid becomes coated with material from the cathode (3), with the eventual result that $\phi_g = \phi_k$, reducing V_{gk} to zero in Eq. 9. Lukirski and others (45) have suggested that where barium or thorium is evaporated from cathode to grid surface, ϕ_g changes until the contaminating layer is bimolecular. A further increase in layer thickness then has no effect on ϕ_g. The role of residual gases can be important, however, because according to Darbyshire (7), Gorelik (6), and Champeix (5), a trace of gas can prevent or reduce such a change of grid work function in tubes having oxide cathodes.

The value ϵ is dependent to a lesser degree upon V_τ in Eq. 9. The average initial velocity of emission will be lowered if the emitting ability of the cathode decreases on life (47). Gray (40) has attributed small drifts in plate current (after temperature equilibrium has been reached) to cathode changes resulting in variations of the average initial velocity of emission.

VII. STABILIZATION OF ϵ BY TUBE PROCESSING

The literature describes several possible methods of stabilizing those physical changes within the tube that cause shifts of correction potential on life. These methods deal mostly with the reduction of the Volta potential ($\phi_k - \phi_g$) by suitable processing. O'Neill (3, 4) has shown how material from the cathode can be evaporated onto the control grid by a series of cathode "hot shots." After the heater voltage is gradually raised to about double the rated value and held at that point for about 30 to 60 seconds, the grid becomes coated with cathode material. No voltage is applied to the other electrodes. If the high heater voltage remains longer than about one minute, the grid becomes too hot and is then decontaminated by evaporation. Repeated application of cathode "hot shots" was found to change the value ϵ toward a level of about 0.55 volt. The grid work function would then presumably equal that of the cathode. O'Neill also cited a test of a type 6SQ7 where no stabilizing hot-shot had been applied, in which the calculated correction potential ϵ decreased from 0.85 at zero hours to about 0.58 at 350 hr. Darbyshire (7) has also reported on the results of applying a high potential to a filament or heater, and he showed how this process increases initial velocity currents. This enhanced I_{vc} from filament to grid could be due to an increase of V_η, or a decrease of V_{gk} or V_m. Darbyshire tabulated two groups of factors which control initial velocity current, and part of his list is given here:

Factors which give high initial velocity current	Factors which give low initial velocity current
1. Flashing the filament on exhaust or on aging	1. Low filament voltage on exhaust or during aging
2. Positive-grid aging	2. Zero or negative grid voltage during aging
3. High emission	3. Low emission due to poisoning or under-activation of filament
4. Low emission due to over-activation of filament	4. Running the filament with no positive potential on the other electrodes

Darbyshire further claimed that if I_{vc} has been increased by flashing the filament during or before aging, the higher value will usually be retained. It is therefore feasible to devise a salvage schedule to increase I_{vc} and keep it stable during life, according to Darbyshire.

Champeix (5) noted that barium is deposited on the control grid of all triodes having oxide-coated cathodes during normal processing, and concluded that changes of V_{gk} over life depended largely on the amount of barium deposited and on the erratic action of residual gases in cleaning up the grid surface. To support his hypothesis, Champeix selected for his experiments 33 shrinkage tubes of type VCL 11, a triode-tetrode with an oxide cathode. All of these tubes which had undergone the usual evacuation and activation, had triode plate currents lower than the rated value at $E_g = 1.0$ volt. Each was then given a special treat-

ment designed to evaporate material from the cathode. The grid was connected to cathode, which was run at 1150° K for 12 hr. with 100 volts on the plate. Normal cathode operation for this type is about 100° K. The results were recorded in detail, and the average values for the group of 33 tubes were as follows:

Triode Section VCL 11 ($\mu = 60$)

	Before treatment	After treatment
I_a at $E_c = 1.0$ v.	0.52 ma.	1.14 ma.
E_c at $I_a = 1.0$ ma.	−0.68 v.	−1.08 v.
I_f	0.84 amp.	0.73 amp.
V_{gk} (Grid-cathode Volta potential measured by Schottky method)	1.14 v.	−0.76 v.

Champeix thus demonstrated that a decrease in Volta potential could be brought about by processing the grids and that plate current of shrinkage tubes of that type could be brought up to rated value. It was further pointed out that the grids could be similarly coated by operating the cathode at 1400° K for one or two minutes with no voltage applied to the plate. Figure 6, based on data by Champeix, gives aver-

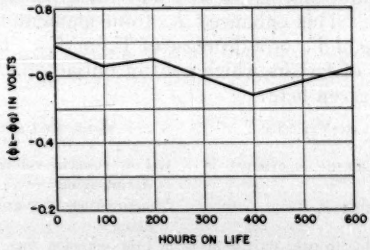


FIG. 6.

age values of V_{gk} for ten tubes of type EF6 that were placed on life. Champeix did not discuss the question of possible primary emission from a coated grid.

The prolonged heating of oxide cathodes at elevated temperatures in order to reduce and stabilize $(\phi_k - \phi_g)$ has been described by Gorelik (6) in an investigation of contact potentials and grid emission. He also noted that $(\phi_k - \phi_g)$ could be stabilized to 0.2–0.25 volt by pre-coating the grids with barium powder or by depositing barium by evaporation from the cathode. This Volta potential, however, was observed to change by as much as 0.5 volt within a few days when there was a slight increase in residual gas in the tube. Of more interest than his grid-coating process is the way Gorelik attacked the problem of thermionic emission from the coated grid wires. Nickel or molybdenum grids which had a coating of Ba and BaO were heated in a manner that could not evaporate excessive amounts of materials from the grid surface.

Coated molybdenum grids, for example, were heated either for several hours at 1000° C., for 1 hr. at 1100° C., or for 20 min. at 1200° C. After any such treatment the grid thermionic emission at normal grid operating temperatures was negligible.

The kind of heat treatment described by Gorelik could not, in all probability, evaporate all the Ba and BaO from the grid surface. Grids treated in such a manner, therefore, could be expected to maintain a relatively low work function throughout life. Ordinarily, a deposit of Ba on the grid would change ϵ but would also cause grid emission at high grid temperatures and secondary emission in the positive grid region. The process described by Gorelik should tend to stabilize ϵ without the undesirable effects of grid emission. Coating grids with substances of *high* work function to reduce grid emission has been discussed by Sorg and Becker (**48**) and by Arditi and DeSantis (**49**).

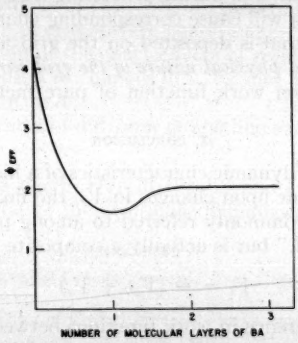


FIG. 7.

VIII. WORK FUNCTION OF CONTAMINATED GRIDS

From Appendix I it can be seen that the work function of a monatomic layer of Ba on a W base is much lower than of either Ba or W in bulk. The contaminated surface also has a lower work function than either of the two metals in the case of a thin layer of Ce, Cs, La, Th, U, or Zr on a base of W, and also for Th on Mo. This phenomenon is obviously due to the existence of some sort of a difference of potential between film and base metal. For Ba on W the effective work function of the surface would be

$$\phi_{eff} = \phi_{Ba} + V_y$$

where V_y is the difference of potential between the Ba film and the W. If the layer of Ba is monatomic the quantity V_y is due to the strong field existing between barium ions and tungsten atoms. For a thick layer of Ba, V_y is zero. Theories of electrical double layers in adsorbed films

have been discussed in detail by Gurney (50), DeBoer (51), Becker (52) and others.

Lukirski (45) claimed that the work function of a surface contaminated with Ba or Th is lowest when the layer has become one molecule thick, and that as layer thickness is then increased ϕ will rise until the layer is bimolecular, after which no further increase of ϕ occurs. Figure 7 is based on data by Lukirski for work function of a Mo grid contaminated with Ba from an oxide-coated cathode.

In the case of Mo covered with a film of alkaline-earth oxides, however, the lowest effective work function may occur when the layer is only 0.001 molecules thick, as seems to be indicated by the findings of Moore and Allison (53).

From the foregoing it is clear that the effective work function of a contaminated grid will change considerably as the nature and thickness of its surface film is altered during processing and on life. This variation of work function will cause corresponding changes in the quantity V_{gk} as cathode material is deposited on the grid and *as residual gases affect the chemical and physical nature of the grid surface* (5, 6, 7, 54, 55). The effect of gases on work function of pure metals is listed in Appendix III.

IX. CONCLUSION

The variations of dynamic characteristics of a high-mu vacuum tube depend to some extent upon changes in V_r, the floating-grid potential. The quantity V_r is commonly referred to among production engineers as "contact potential," but is actually a composite value

$$V_r = -(V_{gk} + V_x) \tag{5}$$

where V_{gk} is the difference in work functions between grid and cathode and V_x is a *spurious* contact difference of potential due to initial velocities, gas, leakage, and other miscellaneous factors contributing to grid current.

Unlike V_r, the internal correction potential ϵ cannot be measured directly. It is a lumped correction factor that is used in space-current equations to account for the voltages V_{gk}, V_{pk}, V_m, and V_η generated internally by the tube. The value ϵ may be conveniently calculated for high-mu triodes by the formula

$$\epsilon = -\frac{E_b}{\mu} - E_c + \frac{nI}{g_m}. \tag{7}$$

Calculations of ϵ are useful in establishing correct tube ratings; measurements of V_r are used in production testing. In a tube having a very good vacuum and a minimum of interelectrode leakage

$$\epsilon \cong -V_r,$$

but otherwise there is no direct relationship between the two quantities. Some of the methods of controlling variations of both ϵ and V_r are:

1. Rigorous cleaning of parts,
2. Efficient gettering,
3. Deposition of cathode material on control grid,
4. Minimizing interelectrode leakage by directional getter flash,
5. Minimizing primary and secondary grid emission by heat-treating the grid or by coating grid with materials of high work function, and
6. Plating grids with Au, Ag, Pt, etc.

Since the exact mechanism of contact potentials in vacuum tubes is not fully understood, the following research objectives are of interest to radio tube engineers:

1. A study of the effects of cathode core materials upon V_{gk},
2. The stabilization of grid surface conditions,
3. The determination of the exact effects of residual gas on V_{gk},
4. A careful evaluation of changes in ϵ, V_r, and V_{gk} over the period of useful tube life, and
5. A study of the rates of diffusion of alkaline earth metals through grid metals.

Acknowledgment is due to Harold Jacobs[5] and Henry W. Parker of Sylvania Electric Products, Inc., for many illuminating discussions.

REFERENCES

(1) R. M. BOWIE, "This Matter of Contact Potential," *Proc. I. R. E.*, Vol. 24, pp. 1501–13 (1936).
(2) G. D. O'NEILL, "The Effect of Contact Potentials on Vacuum Tube Characteristics," paper given at I. R. E. National Convention, Detroit, Mich. June 24, 1941.
(3) G. D. O'NEILL, "The Effects of Grid Contact Potential on Electron Tube Characteristics," paper given at I. R. E. Summer Seminar, Emporium, Pa., August 13, 1948.
(4) G. D. O'NEILL, "The Effects of Grid Contact Potential and Initial Electron Velocity on Electron Tube Characteristics," *The Sylvania Technologist*, Vol. 1, No. 4, pp. 11–12 (1948).
(5) R. CHAMPEIX, "La Mesure des Differences de Potentiel Contact et du Courant de Saturation dans les Tubes a Vide utilisant des Cathodes a Oxydes," *Annales de Radioelectricite*, Vol. 1, pp. 208–34 (1946).
(6) B. V. GORELIK, "Contact Potential Difference and the Emission of the Grids of Radio Tubes" (in Russian), *J. Technical Physics*, Vol. 15, pp. 549–73 (1945).
(7) J. A. DARBYSHIRE, "Initial Velocity Currents in Thermionic Valves," *Proc. Physical Soc.*, Vol. 53, pp. 219–32 (1941).
(8) B. GYSAE AND S. WAGENER, "Zur Frage des Kontaktpotentials," *Zeitschrift für Physik*, Vol. 110, pp. 145–63 (1938).
(9) W. HEINZE, "Uber den Zusammenhang des Kontaktpotentials und der Austrittsarbeit," *Ibid.*, Vol. 109, pp. 459–71 (1938).
(10) P. A. ANDERSON, "The Contact Difference of Potential between Tungsten and Barium-The External Work Function of Barium," *Physical Review*, Vol. 47, pp. 958–64 (1935).

[5] Now at Evans Signal Laboratories, Belmar, N. J.

(11) E. PATAI, "Kontaktpotentials . . .," *Zeitschrift für Physik*, Vol. 59, pp. 697–9 (1930).
(12) N. B. REYNOLDS, "Schottky Effect and Contact Potential Measurements on Thoriated Tungsten Filaments," *Physical Review*, Vol. 35, pp. 158–71 (1930).
(13) G. MÖNCH, "Der Zusammenhang zwischen Austrittsarbeit and Voltaspannung," *Erlanger Berichte*, Vol. 65, pp. 202–7 (1934). See also *Chem. Abstracts*, Vol. 30, p. 5089[6] (1936).
(14) G. MÖNCH, "Vergleich zweier Verfarhren zur Bestimmung von Kontaktspannungen zwischen Metallen," *Zeitschrift für Physik*, Vol. 65, pp. 233–43 (1930).
(15) B. GYSAE AND S. WAGENER, "Zur Temperaturabhangigkeit der Austrittsarbeit von Kathoden mit ungleichmässig emittierender oberfläche," *Ibid.*, Vol. 115, pp. 296–308 (1940).
(16) R. A. MILLIKAN, "The Distinction between the Intrinsic and Spurious Contact E.M.F.'s and the Question of Absorption of Radiation by Metals in Quanta," *Physical Review*, Vol. 18, pp. 236–44 (1921).
(17) J. A. BECKER AND W. H. BRATTAIN, "The Thermionic Work Function and the Slope Intercept of the Richardson Plot," *Ibid.*, Vol. 45, pp. 694–705 (1934).
(18) J. MILLMAN AND S. SEELY, "Electronics," New York, McGraw-Hill Book Co., Inc., 1941 pp. 157–167.
(19) J. A. CHALMERS, "Contact Potentials," *Philosophical Magazine*, Vol. 33, pp. 399–430 (1942).
(20) W. A. ZISMAN, "A New Method of Measuring Contact Potential Differences in Metals," *Review of Scientific Instruments*, Vol. 3, pp. 367–70 (1932).
(21) B. A. ROSE, "Measurements on Contact Potential Difference between Different Faces of Copper Single Crystals," *Physical Review*, Vol. 44, pp. 585–8 (1933).
(22) E. DOWLING, "Contact Electromotive Force between Two Dissimilar Metals," *Ibid.*, Vol. 25, pp. 812–25 (1925).
(23) J. G. POTTER, "Temperature Dependence of the Work Function of Tungsten from Measurement of Contact Potentials by the Kelvin Method," *Ibid.*, Vol. 58, pp. 623–32 (1940).
(24) A. T. WATERMAN AND J. G. POTTER, "Contact Potential between Filaments in Vacuum by the Kelvin Method," *Ibid.*, Vol. 51, p. 63 (1937).
(25) W. E. MEYERHOFF AND P. H. MILLER, JR., "A Modified Kelvin Method for Measuring Contact Potential Differences," *Review of Scientific Instruments*, Vol. 17, p. 15 (1946).
(26) C. W. OATLEY, "The Measurement of Contact Potential Difference," *Proc. Royal Soc.* (London), Vol. A155, pp. 218–34 (1936).
(27) W. SCHOTTKY, "Uber den Austritt von Elektronen aus Glühdrahten bei verzögernden Potentialen," *Annalen der Physik*, Vol. 44, pp. 1011–34 (1914).
(28) H. ROTHE, "Austrittsarbeit und Kontaktpotential," *Zeitschrift für technische Physik*, Vol. 6, pp. 633–8 (1925).
(29) E. L. CHAFFEE, "Thermionic Vacuum Tubes," New York, McGraw-Hill Book Co., Inc., 1933, p. 80.
(30) R. C. L. BOSWORTH AND E. K. RIDEAL, "Studies in Contact Potentials," *Proc. Royal Soc.* (London), Vol. A162, pp. 1–49 (1937).
(31) D. B. LANGMUIR, "Contact Potential Measurements on Tungsten Filaments," *Physical Review*, Vol. 49, pp. 428–35 (1936).
(32) L. H. GERMER, "The Distribution of Initial Velocities among Thermionic Electrons," *Ibid.*, Vol. 25, pp. 795–809 (1925).
(33) C. DAVISSON AND L. H. GERMER, "The Thermionic Work Function of Tungsten," *Ibid.*, Vol. 20, pp. 300–30 (1922).
(34) L. R. KOLLER, "Electron Emission from Oxide-Coated Filaments," *Ibid.*, Vol. 25, pp. 671–6 (1925).
(35) I. LANGMUIR, "The Effect of Space Charge and Initial Velocities on the Potential Distribution and Thermionic Current between Parallel Plane Electrodes," *Ibid.*, Vol. 21, pp. 419–35 (1923).
(36) G. F. METCALF AND B. J. THOMPSON, "A Low Grid-Current Vacuum Tube," *Ibid.*, Vol. 36, pp. 1489–94 (1930).

(37) C. E. NIELSEN, "Measurement of Small Currents," *Review of Scientific Instruments*, Vol. 18, pp. 18–31 (1947).
(38) C. D. GOULD, "Subminiature Electrometer Tube," *Electronics*, Vol. 20, No. 3, pp. 106–9 (1947).
(39) E. E. STAFF, M. I. T., "Applied Electronics," New York, John Wiley and Sons, Inc., 1943, p. 230.
(40) G. E. VALLEY AND H. WALLMAN, "Vacuum Tube Amplifiers," New York, McGraw-Hill Book Co., Inc., 1948, pp. 418–22, 730.
(41) C. H. THOMAS, "Soft X-Rays from Iron," *Physical Review*, Vol. 25, pp. 322–32 (1925).
(42) H. J. VAN DER BIJL, "Thermionic Vacuum Tubes," New York, McGraw-Hill Book Co., Inc., 1920, p. 46.
(43) F. E. TERMAN, "Radio Engineering," New York, McGraw-Hill Book Co., Inc., 1937, p. 118.
(44) H. J. REICH, "Principles of Electron Tubes," New York, McGraw-Hill Book Co., Inc., 1941, p. 51.
(45) W. G. DOW, "Fundamentals of Engineering Electronics," New York, John Wiley and Sons, Inc., 1944, p. 197.
(46) P. LUKIRSKY, A. SOSINA, S. WEKSHINSKY, AND T. ZAREWA, "Versuche über die Eigenschaften der Atomschichten," *Zeitschrift für Physik*, Vol. 71, pp. 306–24 (1931).
(47) "Selecting Proper Tubes and Circuits," *Electronic Industries*, Vol. 5, No. 9, p. 72 (1946).
(48) H. E. SORG AND G. A. BECKER, "Grid Emission in Vacuum Tubes," *Electronics*, Vol. 18, No. 7, pp. 104–9 (1945).
(49) M. ARDITI AND V. J. DESANTIS, "Thermionic Emission from Grids in Vacuum Tubes," paper given at I. R. E. National Convention, New York, March 23, 1948.
(50) R. W. GURNEY, "Theory of Electrical Double Layers in Adsorbed Films," *Physical Review*, Vol. 47, pp. 479–82 (1935).
(51) J. H. DEBOER, "Electron Emission and Adsorption Phenomena," London, Cambridge University Press, 1935, pp. 16, 25, 142–62.
(52) J. A. BECKER, "The Life History of Adsorbed Atoms and Ions," *Trans. Electrochemical Soc.*, Vol. 55, pp. 153–75 (1929).
(53) G. E. MOORE AND H. W. ALLISON, "Thermionic Effects of Thin Films of Alkaline Earth Oxides on Metals," *Physical Review*, Vol. 65, p. 254 (1944).
(54) O. W. RICHARDSON AND F. S. ROBERTSON, "The Effect of Gases on the Contact Difference of Potential between Metals of Different Temperatures," *Philosophical Magazine*, Vol. 43, pp. 162–74 (1922).
(55) E. DUBOIS, "The Volta Effect," *Annales de Physique*, Vol. 14, pp. 627–725 (1930).
(56) A. A. FROST AND V. R. HURKA, "Adsorption of Vapors at Solid Surfaces and the Change of Surface Electrical Potential," *J. Am. Chemical Soc.*, Vol. 62, pp. 3335–40 (1940).
(57) A. A. FROST, "Measurement of Surface Potential or Contact Potential Differences," *Review of Scientific Instruments*, Vol. 17, pp. 266–8 (1946).
(58) A. L. REIMANN, "The Contact Potential Difference between Clean and Oxygenated Tungsten," *Philosophical Magazine*, Vol. 20, pp. 594–607 (1935).
(59) N. K. ADAM, "The Physics and Chemistry of Surfaces," London, Oxford University Press, 1941, pp. 307–13.
(60) H. CASSEL AND E. GLÜCKAUF, "Influence of Oxygen on Thermionic Emission from Platinum," *Zeitschrift für Physikalische Chemie*, Vol. B18, Nos. 4–5, pp. 347–59 (1932).
(61) H. K. WHALLEY AND E. K. RIDEAL, *Proc. Royal Soc.*, Vol. A140, p. 484–504 (1933).
(62) C. ZWIKKER, "Thermionic Emission of the Metals Tungsten, Molybdenum, Thorium, Zirconium, and Hafnium," *Proc. Royal Academy of Amsterdam*, Vol. 29, No. 6, pp. 792–802 (1926).
(63) E. DUBOIS, "Sur l'effet Volta, Influence de l'oxydation des electrodes," *Comptes Rendus*, Vol. 189, p. 1260 (1929).
(64) A. L. REIMANN, "Thermionic Emission," London, Chapman and Hall, 1934, pp. 36–43.
(65) I. LANGMUIR AND K. T. COMPTON, "Electrical Discharges in Gases, Part II. Survey of Fundamental Processes," *Reviews of Modern Physics*, Vol. 2, pp. 144–146 (1930).

(66) H. GROVER, "Thermionic Emission of Positive Ions from Molybdenum," *Physical Review*, Vol. 52, pp. 982–6 (1937).
(67) R. C. L. BOSWORTH, "Contact Potential of Nickel," *Trans. Faraday Soc.*, Vol. 35, pp. 397–402 (1939).
(68) L. A. DUBRIDGE AND W. W. ROEHR, "The Thermionic and Photoelectric Work Functions of Molybdenum," *Physical Review*, Vol. 42, pp. 52–7 (1932).
(69) "International Critical Tables," New York, McGraw-Hill Book Co., Inc., 1929, Vol. VI, pp. 53–4.
(70) C. J. GALLAGHER, "Adsorption of Thorium on Tantalum," *Physical Review*, Vol. 65, pp. 46–50 (1944).
(71) S. DUSHMAN, "Thermionic Emission," *Reviews of Modern Physics*, Vol. 2, pp. 381–476 (1930).
(72) E. NISHIBORI AND H. KAWAMURA, "The Conductivity and Thermionic Emission of the Oxide Cathode," *Proc. Physico-Mathematical Soc. of Japan*, Vol. 22, pp. 378–84 (1940).
(73) J. P. BLEWETT, "Properties of Oxide-Coated Cathodes II," *J. Applied Physics*, Vol. 10, pp. 831–48 (1939).
(74) C. G. FOUND, "A New Method of Investigating Thermionic Cathodes," *Physical Review*, Vol. 45, pp. 519–26 (1934).
(75) K. R. SPANGENBERG, "Vacuum Tubes," New York, McGraw-Hill Book Co., Inc., 1948, p. 44.
(76) L. R. KOLLER, "Electron Emission from Oxide-Coated Filaments," *Physical Review*, Vol. 25, pp. 671–6 (1925).
(77) H. JACOBS, "Dissociation Energies of Surface Films of Various Oxides as Determined by Emission Measurements of Oxide Coated Cathodes," *J. Applied Physics*, Vol. 17, pp. 596–603 (1946).
(78) J. D. COBINE, "Gaseous Conductors," New York, McGraw-Hill Book Co., Inc., 1941, p. 109.

Additional References

(79) "The Effect of Contact Potential on Zero Bias Operation," *Sylvania Engineering News Letter*, No. 89, January 30, 1948.
(80) "Zero Bias Operation of High Mu Triodes," *Ibid.*, No. 50, August 2, 1938.
(81) F. I. WRIGHT, "Note on the Energy Distribution of Electrons Emitted from a Hot Filament," *Leeds Philosophical and Literary Soc.*, Vol. 3, pp. 526–31 (1939).
(82) O. KLEMPERER, "Influence of Space Charge on Thermionic Emission Velocities," *Proc. Royal Soc.* (London), Vol. A190, pp. 376–93 (1947).
(83) B. C. L. BOSWORTH, "Contact Potential Difference as a Tool in the Study of Adsorption," *J. Proc. Royal Soc.*, N. S. Wales, Vol. 79, pp. 53–62 (1946).
(84) B. GYSAE AND S. WAGENER, "Der Einfluss des Kontaktpotentials auf die Kennlinnie von Emfänger and Senderöhren," *Zeitschrift für technische Physik*, Vol. 19, pp. 264–9 (1938).
(85) H. ROTHE, "Untersuchungen über den Gitterstrumensatzpunkt bei Verstarkerrohren," *Telefunken-Zeitschrift*, Vol. 13, No. 61, pp. 45–51 (1932).
(86) W. B. NOTTINGHAM, "Spurious Contact Potentials and 'Trapped' Electrons," *Physical Review*, Vol. 39, p. 183 (1932).
(87) O. W. RICHARDSON AND F. S. ROBERTSON, "Contact Difference of Potential and Thermionic Emission," *Philosophical Magazine*, Vol. 43, p. 557 (1922).
(88) W. B. NOTTINGHAM, "Measurement of the Effect of Light on Spurious Contact Potentials and 'Trapped' Electrons," *Physical Review*, Vol. 44, p. 311 (1933).
(89) F. A. VICK, "Contact Potentials," *Science Progress*, Vol. 32, pp. 504–9 (1938).
(90) F. A. MAXFIELD AND R. R. BENEDICT, "Theory of Gaseous Conduction and Electronics," New York, McGraw-Hill Book Co., Inc., 1941, pp. 160–2, 185–6.
(91) L. B. HEADRICK AND E. A. LEDERER, "Films formed on Electrodes during Activation of Oxide-Coated Cathodes," *Physical Review*, Vol. 50, p. 1094 (1936).
(92) LORD KELVIN, "Contact Electricity of Metals," *Philosophical Magazine*, Vol. 46, pp. 82–120 (1898).

APPENDIX I

THERMIONIC WORK FUNCTIONS

Element	ϕ in volts	Monolayer	ϕ in volts	Reference
Ag	4.03			
Al	4.08*	Ba on W	1.56	64
Au	4.58			
Ba	2.11	Ba & O on W	1.34	64
Be	3.92*			
		Ce on W	2.71	64
Bi	4.31*		2.72	65
C	4.39			
Ca	2.24	Cs on W	0.72	65
Cb	3.96		1.6	59
Cd	3.94*		1.36	64
Ce	2.6	Cs & O on W	0.71	59
Cr	4.60			
Cs	1.81	La on W	2.71	64
Cu	4.38		2.72	65
Fe	4.77			
		O on Mo	8.0	66
Ga	4.12*			
Ge	4.73*	O on Ni	6.36	67
Hg	4.52*			
Ir	4.57	O on W	9.23	59
K	2.24*			
		Na on Ni	0.6	67
La	3.30			
Li	2.28*	Th on Mo	2.59	64
Mg	3.68*		2.61	68
Mo	4.20			
Mn	3.76*	Th on W	2.61	68
			2.63	69
Na	2.28*			
Ni	5.03	Th on W		
Os	4.7	($\frac{1}{3}$ covered)	3.20	59
Pb	3.97*			
Pd	4.99	Th on Ta	2.52	70
		U on W	2.84	65
Pt	5.32			
Re	5.1	Zr on W	3.14	64
Rb	2.16*		3.15	65
Rh	4.58			
Ru	4.52			
Sb	4.01*			
Sr	2.74*			
Sn	4.38			
Ti	3.95*			
U	3.27			
V	4.44			
W	4.52			
Zn	4.24*			
Zr	4.12			

* From photoelectric measurements.

THERMIONIC WORK FUNCTIONS

Oxide	Base	ϕ in volts	Reference
Al_2O_3	Pt	3.90	69
	?	3.77	71
BaO	?	0.95	72
	?	1.1	73
	Pt	1.68	69
	?	1.96	74
(BaSr)O	?	1.0	75
	?	1.05	76
	?	1.51–1.89	65
BeO	Pt	3.94	69
CaO	?	1.9	73
	?	2.19	65
		2.24	71
	Pt	2.52	69
CdO	Pt	2.43	69
Co_2O_3	Pt	4.06	69
CuO	Pt	1.76	69
CuO*	Cu	4.35	77
FeO*	Fe	3.85	77
Fe_2O_3	Pt	3.82	69
MgO	?	1.02	65
	Pt	3.31	69
MoO_3*	Mo	4.25	77
NiO	Pt	4.19	69
	?	4.87	71
NiO*	Ni	5.55	77
SrO	Pt	1.86	69
	?	1.4	73
Ta_2O_5*	Ta	4.65	77
ThO_2	?	2.94	71
	Pt	3.18	69
TiO_2	Pt	4.24	69
WO_3*	W	4.95	77
ZrO_2	?	3.4	71
	Pt	4.2	69
ZrO_2*	Zr	4.75	77

* Very thin film.

APPENDIX II

EFFECTS OF PHYSICAL FACTORS ON V_r, THE FLOATING GRID POTENTIAL (FIG. 5)

	Cause negative shift of V_r	Cause positive shift of V_r
Increase of:	initial velocities of emitted electrons from cathode secondary emission from plate	residual gas * grid-cathode leakage grid-plate leakage primary grid emission photoelectric grid emission grid work function

* Deterioration of vacuum in the tube will result in an increase of gas current in the grid circuit, *tending* to shift V_r to a more positive value. The effects of gases and vapors on grid work function, however, are very great; ϕ is raised by some gases and lowered by others, as shown in Appendix III. Shift of V_r on life, then, is an extremely complex phenomenon, and does not depend upon any single physical or chemical change within the tube.

APPENDIX III

EFFECTS OF GASES AND VAPORS ON WORK FUNCTION *

	Effect of Gas on ϕ			Effect of Gas on ϕ	
Metal	Decrease	Increase	Metal	Decrease	Increase
Ag	H_2	O_2, N_2, CN	Mo	H_2O	
Au	H*	Air	Na	O_2, S, H_2O	
Bi		Air	Ni	H_2O	Air, O_2
C	NH_3, H_2, CO_2, Air		Pd	H_2, O_2	O_2
			Pt	H_2, NH_3	O_2
Fe	O_2, H_2		Rh		H_2, O_2
Hg	Wax vapor, H_2O vapor	H_2O (trace)	Ta	H_2O	
K	H_2, O_2, H_2O S, NO		W	H_2O	O_2

* Data from L. A. DUBRIDGE, "Photoelectric Phenomena." New York, McGraw-Hill Book Co., Inc., 1932.

New Naval Stores Product.—Maleo-pimaric acid, a new naval stores product developed by the Department of Agriculture, has possibilities for use in the preparation of plasticizers, resins, and emulsifying agents. The development has reached a stage where commercial testing is feasible and where samples for tests are available on request to prospective users.

Recent work on maleo-pimaric acid has been financed by funds provided under the Research and Marketing Act of 1946, and has been carried out at the Naval Stores Station in Olustee, Florida, pilot plant of the Naval Stores Research Division. The pilot-plant investigations have been based on earlier laboratory-scale research and on a process for refining oleoresin, covered by U. S. Patent No. 2,359,980 granted to a member of the Naval Stores Research Division and assigned to the Secretary of Agriculture for licensing to responsible firms and individuals on a royalty-free, nonexclusive basis.

Maleo-pimaric acid is the adduct—addition product—of maleic anhydride with the levopimaric acid of pine gum. It is a white, crystalline, tribasic product with an acid number in acetone solution of 420 and a molecular weight of 400. The pure product (produced in small quantities in the laboratory) melts at 229° to 230° C. while maleo-pimaric acid produced in the pilot plant has a slightly lower melting point (222° to 225° C.). Maleo-pimaric acid is soluble in acetone, ether, alcohol, and aromatic solvents, and is practically insoluble in aliphatic hydrocarbons.

The properties of the maleo-pimaric acid are such that it should find successful application in alkyde-type resins and in sizing agents.

The low volatility of its alkyl esters and their compatibility with many resins indicates promise as a plasticizing agent.

The soap of the ethyl maleo-pimaric acid has been evaluated on a pilot-plant scale as an emulsifier in the preparation of a synthetic rubber. The rubber produced compares favorably in quality with standard GR-S 10.

Concerns or individuals interested in testing this product for possible commercial application may obtain samples by writing to the Naval Stores Research Division, Southern Regional Research Laboratory, Bureau of Agricultural and Industrial Chemistry, 2100 Robert E. Lee Boulevard, New Orleans 19, Louisiana.

Worn-out, cemented linoleum can be removed handily with the use of a pneumatic hammer and a simple scaling tool which any shop can make, according to a mechanic at the Philadelphia Naval Shipyard. A 30-inch shank of a size to fit the hammer, with a 6-inch scaling blade attached to it, does the job. Older methods involve hand removal with a chisel.

A central clearing-house for technical documents of the Defense Department and its contractors, encompassing technology of Army, Navy and Air Force research and development activities, is being set up at Wright-Patterson Air Force Base. The three services will operate the unified agency along the lines of the former Central Air Documents Office (Navy-Air Force).

THE INFLUENCE OF THE TEMPERATURE AND THE PERIOD OF KEEPING UPON THE BIOCHEMICAL CHANGES IN THE COMMON FOWL *GALLUS DOMESTICUS*[1]

BY

JOSEPH SAMUEL HEPBURN[2]

Part II[3]

CHILL ROOM STORAGE

The temperature of the mechanically refrigerated chill room was determined by means of a recording thermograph. It ranged between −2.8° and 1.1° C., and had an average value of 0° C. Samples were kept at this temperature for periods as long as 21 days.

In these and certain other experiments, a number of fowls were carefully eviscerated with aseptic precautions leaving the abdominal adipose tissue *in situ*, then sawn into bilaterally symmetrical halves: one-half of each bird was analyzed at once; the other half, as free as possible from bacterial contamination, was turned cut side down into a shallow tray of sterile, melted paraffin. The body cavity of the bird was thereby sealed, and the half bird became comparable to a whole specimen so far as bacterial contamination and air access were concerned. It was then placed under the experimental environment (chill room or household refrigerator) for a suitable period of time, after which it was analyzed as the first half had been. Each of these subsequent samples consisted of a group of five halves.

The analytical results on the gross composition of the meat show a slight, but appreciable increase in the water content, more so in the light meat than in the dark meat. This change may be related to the humidity of the chill room which was determined by means of a recording hygrothermograph and found to lie between 80 and 96 per cent, with an average value of 82 per cent. Some evidence of proteolysis in the light meat is given by the decrease in protein content and the increase in creatinine content.

The nitrogen partition showed a decrease in the total nitrogen of the aqueous extract in both the light meat and the dark meat; this doubtless was due to a transformation of a portion of the water-soluble protein of the fresh birds into a protean or other insoluble primary derived protein.

[1] Dissertation submitted to the Committee on Higher Degrees in Course of the Hahnemann Medical College and Hospital of Philadelphia, in partial fulfillment of the requirements for the Degree of Doctor of Chemistry, 1946.

[2] Professor of Chemistry and Research Associate in Gastroenterology, Hahnemann Medical College, Philadelphia, Pa.

[3] Part I was published in this JOURNAL, Vol. 249, No. 5, May, 1950, p. 393.

TABLE VII.—*Chickens Kept in a Mechanically Refrigerated Chill Room*

	Fresh 3 samples 40 birds	Average Period in Chill Room 14 days 3 samples 15 birds	21 days 3 samples 15 birds
Gross Composition			
Light Meat			
Water	73.54	73.99	73.85
Ether Extract	1.36	1.35	1.24
Ash	1.20	1.15	1.11
Protein	22.03	21.76	21.66
Creatinine	1.11	1.15	1.23
Dark Meat			
Water	73.04	73.27	73.19
Ether Extract	5.45	4.89	4.93
Ash	1.06	1.09	1.09
Protein	19.71	19.22	19.06
Creatinine	0.87	0.87	0.89
Partition of Total Nitrogen of Meat			
Light Meat			
Total nitrogen of aqueous extract	26.08	21.25	23.38
Coagulable nitrogen of aqueous extract	9.40	7.27	8.02
Proteose nitrogen	0.662	0.513	0.549
Amino acid and basic nitrogen	9.20	9.67	10.31
Peptone nitrogen	6.82	3.79	4.50
Ammoniacal nitrogen by aeration	0.332	0.333	0.371
Dark Meat			
Total nitrogen of aqueous extract	19.41	18.24	19.11
Coagulable nitrogen of aqueous extract	9.69	7.14	7.92
Proteose nitrogen	0.715	0.662	0.759
Amino acid and basic nitrogen	8.16	8.31	8.59
Peptone nitrogen	0.85	2.13	1.85
Ammoniacal nitrogen by aeration	0.297	0.404	0.439
Fat			
Iodine Number	71.3	73.9	73.6
Saponification Number	185.7	187.9	193.4
Acid Value	0.6	1.4	2.3
Ester Value	185.1	186.5	191.1
Hehner Number	95.08	91.19	95.18
Percentage Free Acid as Oleic	0.30	0.69	1.15
Index of Refraction	1.4621	1.4619	1.4598
Acid Value of Crude Abdominal Fat (2 samples)	0.67	0.91	0.92

The most striking changes were the progressive increases in the amino acid and basic nitrogen of both kinds of meat. Incidentally, the ammoniacal nitrogen of the meat, as determined by aeration (11),[4] also increased.

In the fat, the most striking change was the progressive increase in its acid value. Likewise, the acid value of the crude fat or adipose tissue (12) also increased.

HOUSE REFRIGERATOR

The chickens (fowls) for this aspect of the research were prepared as described in the preceding section. The refrigerator was cooled by means of ice; its temperature was determined by means of a recording thermograph and found to range between 7.2° and 12.8° C. The maxi-

[4] The boldface numbers in parentheses refer to the references appended to this paper.

mum period of keeping at this temperature was 7 days. Both the light meat and the dark meat underwent slight, but definite, changes in gross composition: a decrease in water content, a decrease in protein content, and an increase in creatinine content. The nitrogen partition revealed proteolysis, since values higher than the initial appeared in the chickens kept in the refrigerator. In the light meat, this was true of the total nitrogen of the aqueous extract, the proteose nitrogen, and the amino

TABLE VIII.—*Chickens Kept in an Iced Refrigerator*

		Period in Refrigerator	
	Fresh 3 samples 35 birds	5 days 2 samples 10 birds	7 days 1 sample 5 birds
Gross Composition			
Light Meat			
Water	73.73	73.23	73.63
Ether Extract	1.32	1.66	1.51
Ash	1.18	1.23	1.20
Protein	21.94	21.47	21.44
Creatinine	1.31	1.62	1.35
Dark Meat			
Water	73.85	73.42	73.55
Ether Extract	4.54	4.98	4.80
Ash	1.08	1.12	1.14
Protein	19.58	19.07	19.13
Creatinine	0.91	1.04	1.03
Partition of Total Nitrogen of Meat			
Light Meat			
Total nitrogen of aqueous extract	24.83	25.07	26.30
Coagulable nitrogen of aqueous extract	10.38	10.38	9.59
Proteose nitrogen	0.560	0.658	0.803
Amino acid and basic nitrogen	10.74	13.14	11.22
Peptone nitrogen	3.13	1.13	4.69
Ammoniacal nitrogen by aeration	0.364	0.396	0.598
Dark Meat			
Total nitrogen of aqueous extract	20.58	19.32	21.65
Coagulable nitrogen of aqueous extract	8.10	7.96	8.11
Proteose nitrogen	0.641	0.591	0.944
Amino acid and basic nitrogen	8.51	9.86	9.74
Peptone nitrogen	3.32	0.91	2.86
Ammoniacal nitrogen by aeration	0.318	0.384	0.802
Fat			
Iodine Number	69.0	65.4	75.4
Saponification Number	184.0	181.8	195.8
Acid Value	0.7	1.7	10.5
Ester Value	183.3	180.1	185.3
Hehner Number	90.02	88.11	97.07
Percentage Free Acid as Oleic	0.35	0.83	5.28
Index of Refraction	1.4608	1.4587	1.4605

acid and basic nitrogen at both 5 days and 7 days, and of the peptone nitrogen at 7 days. In the dark meat, it was true of the total nitrogen of the aqueous extract and the proteose nitrogen at 7 days, and of the amino acid and basic nitrogen at both 5 and 7 days. Additional evidence of protein cleavage was shown by the progressive increase in both the light meat and the dark meat, of the ammoniacal nitrogen determined by aeration.

In the fat, the acid value increased, especially during the last two days in the refrigerator.

ROOM TEMPERATURE

In the studies concerning the biochemical changes at room temperature, 3 roasters were used in each pair of experiments, they were eviscerated and sawn into bilaterally symmetrical halves, one-half of each bird was used for the fresh sample; the other halves were sealed by means of molten paraffin as described in the section on Chill Room Storage, kept in the room for definite periods of time, then analyzed. Accordingly, the results on the same birds are presented in adjacent columns. The temperature of the room was from 19.4° to 26.7° with an average of 23.9° C. Four experiments were made; the period of keeping at room temperature was 2 days in each of two experiments, 3 days in one experiment, and 4 days in one experiment.

TABLE IX.—*Chickens Kept at Room Temperature*

Days at Room Temperature	2		3		4	
Number of Samples	Average of 2		1		1	
Number of Birds	6		3		3	
	Fresh	Stored	Fresh	Stored	Fresh	Stored
Gross Composition						
Light Meat						
Water	73.96	73.47	74.20	74.39	73.40	74.43
Ether Extract	1.82	1.81	1.56	1.12	1.97	2.38
Ash	1.26	1.23	1.15	1.13	1.19	1.21
Protein	21.16	21.32	20.94	20.69	21.50	19.81
Creatinine	1.41	1.84	1.44	1.86	1.48	2.06
Dark Meat						
Water	74.02	73.84	74.27	73.94	74.28	74.89
Ether Extract	3.40	4.02	4.45	5.87	3.18	3.92
Ash	1.22	1.19	1.15	1.07	1.14	1.24
Protein	19.91	19.19	18.63	16.38	19.81	17.81
Creatinine	1.02	1.45	1.00	1.60	1.05	1.90
Partition of Total Nitrogen of Meat						
Light Meat						
Total nitrogen of aqueous extract	24.48	28.52	26.59	34.65	25.26	33.94
Coagulable nitrogen of aqueous extract	9.45	8.18	12.05	13.22	10.97	10.16
Proteose nitrogen	0.58	1.22	0.604	2.05	0.36	2.79
Amino acid and basic nitrogen	11.77	14.77	12.15	15.09	12.14	17.26
Peptone nitrogen	2.69	4.35	1.78	4.30	1.84	3.73
Dark Meat						
Total nitrogen of aqueous extract	18.84	26.64	19.76	32.27	19.32	37.28
Coagulable nitrogen of aqueous extract	8.09	8.87	8.76	11.82	8.40	12.34
Proteose nitrogen	0.53	1.13	0.697	1.76	0.48	2.20
Amino acid and basic nitrogen	9.28	13.11	9.79	16.42	9.66	17.66
Peptone nitrogen	0.95	3.54	0.515	2.24	0.77	5.09
Fat						
Iodine Number	64.9	67.1	66.2	61.2	64.0	63.3
Saponification Number	181.7	184.2	171.5	174.4	182.6	191.0
Acid Value	1.4	5.6	0.5	25.4	0.4	46.2
Ester Value	180.3	178.6	171.0	149.0	182.2	144.8
Hehner Number	83.14	86.74	81.0	81.9	86.1	90.8
Percentage Free Acid as Oleic	0.70	2.79	0.25	12.76	0.20	23.23
Index of Refraction	1.4572	1.4606	1.4597	1.4566	1.4605	1.4575

The chief changes in gross composition of the meat were a decrease in its protein content and an increase in its creatinine content.

In the nitrogen partition, marked evidence of proteolysis appeared. In the dark meat, invariably the total nitrogen of the aqueous extract and each of its components increased; in the light meat, the total nitrogen of the aqueous extract and each of its components except the coagulable nitrogen increased. If the *increase* in amino acid and basic nitrogen be used as the measure of proteolysis, then, in the dark meat, the increase (final percentage minus initial percentage) was progressive, being 3.83, 6.63, and 8.00, respectively, at 2, 3, and 4 days, while in the light meat the increase was approximately the same (3.00 and 2.94) at 2 and 3 days, and attained its maximum (5.12) at 4 days.

In the fat, the most striking and uniform change was the progressive increase in the acid value, the actual increase (final value minus initial value) being 4.2, 29.4, and 45.8, respectively, at 2, 3, and 4 days. In fact, almost one-quarter of the glycerides had been hydrolyzed at the end of 4 days. As a result of these increases in acid value, the ester value decreased progressively.

INFLUENCE OF TEMPERATURE OF KEEPING UPON BIOCHEMICAL CHANGES

The *increase* in amino acid and basic nitrogen during keeping of roasters in the room for 2 days (light meat 3.00 per cent, dark meat 3.83 per cent) was in excess of the increase in that component of the muscles of fowls during keeping for 5 to 7 days in an iced refrigerator (light meat 0.48 to 2.40 per cent, dark meat 1.23 to 1.35 per cent), or during chill room storage of fowls for 14 to 21 days (light meat 0.47 to 1.11 per cent, dark meat 0.15 to 0.43 per cent), or in roasters stored hard frozen for 16 months (light meat 2.72 to 2.82 per cent, dark meat 1.19 to 1.73 per cent). This increase usually was at the expense of the proteoses and the peptones, occasionally at the expense of more complex proteins. It was due to native proteases of the tissues. The infrequent occurrence and low counts of liquefying microorganisms, reported below, excludes them as a prominent factor in the proteolysis.

The *increase* in acid value in roasters kept for 2 days in the room (4.2) was in excess of that in fowls kept in an iced refrigerator for 5 days (1.0), or in fowls stored in the chill room for 21 days (1.7), or in eviscerated roasters stored hard frozen for 16 months (3.9), and somewhat less than that in uneviscerated roasters stored hard frozen for 16 months (5.9).

The above figures are based on the average values. The increase in acid value was due to lipase, a native enzyme of the adipose tissue (13, 14) which is active at the temperature of the incubator, the household refrigerator, the mechanically refrigerated chill room and the freezer (15), and has been shown to hydrolyze chicken fat (16).

The simultaneous change in the same direction of the saponification number and the Hehner number, often noted, apparently is related to

the beta oxidation of fatty acids, and has been simulated by oxidation of chicken fat with dilute (3 per cent) hydrogen peroxide at the temperature of the water bath (17, 18). Oxidizing enzymes have been found in the adipose tissue of the chicken (19). Reviews concerning the influence of low temperatures upon enzymes have been published by the author (20, 21).

BACTERIOLOGICAL STUDIES

Cultures made from superficial and deep muscles, blood, and liver of chickens as quickly as possible after killing showed those organs to be sterile. A very general and fairly rapid invasion of the musculature by bacteria occurred. Bacterial counts were made of the skin and of the subcutaneous muscles of the inner thigh and of the breast in 7 groups of chickens which had been kept at a temperature of 0° C. for 24 hr. after killing, then sampled, also in 8 groups of birds which had been kept at a temperature of −15° C. for 48 to 72 hr. after killing, then sampled. None of the samples was sterile. Plates of nutrient agar for aerobic plus facultative bacteria were incubated at temperatures of 37°, 20°, and 0° C. In the muscles, the plates incubated at 20° C. showed the highest counts per gram of tissue in 18 out of the 30 samples; their count was less than 200 in at least one half the samples; the lowest count was 0, the highest 9300. The plates incubated at 37° C. showed counts as low as 0 and as high as 28,000; the count was below 200 in 20 of the samples. The plates incubated at 0° C. showed from 9 to 75 bacteria per gram in 10 of the samples. Liquefying organisms were counted on nutrient gelatin plates incubated at 20° C.; they were present in 16 of the samples in numbers between 5 and 375 per gram.

The counts in the skin almost invariably were higher than those in the muscle. Upon comparison of the skin counts at the three temperatures, they were highest in the plates incubated at 20° C. in 16 samples and in those incubated at 37° C. in 10 samples. The counts at 20° C. ranged between 130 and 17,500 and exceeded 200 in 25 samples. The counts at 37° C. ranged between 35 and 30,500, and exceeded 200 in 24 samples. Bacteria proliferating at 0° C. were present in the skin of each sample; their count ranged between 12 and 2200. Liquefying organisms, growing on nutrient gelatin plates incubated at 20° C., were present in 10 of the samples in numbers between 14 and 80 per gram.

Microorganisms producing gas in glucose broth occurred in but 6 samples of skin and 6 samples of muscle.

In another group of fresh chickens (mature hens), 11 samples were analyzed in the packing house (23), the bacterial count of the abdominal wall was determined. The number of bacteria per gram ranged between 14 and 448 in undrawn (uneviscerated) birds and between 2000 and 266,000 in fully drawn (eviscerated) birds.

In the chickens which had been stored hard frozen, the subcutaneous

muscles of the breast, those of the inner thigh, and the abdominal wall were examined separately for each of the following groups: (*a*) Aerobic plus facultative bacteria, (*b*) anaerobic plus facultative bacteria, (*c*) anaerobic plus facultative bacteria resistant to a temperature of 80° C. for 10 minutes (spore-forming microorganisms of putrefaction), and (*d*) liquefying bacteria. At times, tests were also made for bacteria of fermentation.

During storage hard frozen, bacteria in the muscles and in the abdominal wall survived, and were able to proliferate when innoculated into nutrient media and then incubated. During storage the number of bacteria per gram of muscle tended to decrease; thus, considering collectively the results at all 3 temperatures of incubation and on both thigh and breast muscle, the aerobic plus facultative bacteria were below 200 per gram in 58 per cent of the counts on fresh birds, and in 65 per cent of the counts on stored birds. Likewise these organisms were below 200 per gram in the abdominal wall in but 19 per cent of the counts on fresh birds and in 42 per cent of the counts on stored birds.

When plates were innoculated for the development of anaerobic plus facultative bacteria, one-third of the cultures from breast and thigh muscle were positive; as were four-ninths of those from abdominal wall cultures. The count per gram was below 200 in 84 per cent of the positive cultures from the breast and thigh muscles and in 45 per cent of the positive cultures from the abdominal wall.

Liquefying microorganisms developed upon one-fifth of the plates innoculated with muscle from the breast or thigh, and upon one-fourth of those innoculated with abdominal wall. The count per gram was below 200 in 84 per cent of the positive plates from the muscles of the thigh and the breast, and in 25 per cent of the positive plates from the abdominal wall.

Tests for bacteria of fermentation were made on 31 chickens, stored for 8 or more months. Bacteria producing gas in lactose broth were found in but 1 sample of breast muscle, and 3 samples of abdominal wall, and never in the thigh muscle. Bacteria producing gas in glucose broth were found in but one sample of the thigh muscle, and 3 samples of abdominal wall, and never in the breast muscle.

The bacteriological examination of the flesh of chickens kept in a mechanically refrigerated chill room included determination of the count of aerobic and facultative bacteria, the count of liquefying bacteria, and the presence of organisms of fermentation. The skin and the subcutaneous muscles of the breast and of the inner thigh were examined separately. The count of aerobic and facultative bacteria increased in the skin and, to a lesser extent, in the muscles of the breast and the thigh. The plates incubated at 20° and 0° usually showed higher counts than did those incubated at 37°. The highest counts per gram were 3,000,000,000 (on a 20° plate) in the skin and 31,000 (on a 37° plate) in

the breast muscle of birds held in the chill room for 21 days. Liquefying bacteria formed but a small fraction of the total count. The maximum number of liquefying bacteria per gram was 3,300,000 in the skin of birds kept in the chill room for 21 days, and 2600 in the breast muscle of birds kept there for 15 days. When tests were made for bacteria producing gas in either lactose broth or glucose broth, the result was positive 7 times in specimens of skin from fresh birds and 15 times in specimens of their skin after chill room storage, 3 times in the specimens of subcutaneous muscle from fresh birds, and 3 times in the specimens of such muscle after chill room storage. Any increase in frequency of occurrence was limited to the skin, and did not extend to the muscles.

The bacteriological examination of the chickens kept in an iced household refrigerator was the same as made on chickens kept in the chill room. The counts increased with the period of keeping; and the increase was more pronounced in the skin than in the muscles. The maximum counts of aerobic plus facultative organisms were: in the skin, 5,200,000 (on the 20° plates) after keeping for 5 days, and 54,000,000 (on the 0° plates) after keeping for 7 days: in the subcutaneous muscles, 900 after keeping for 5 days and 73,000 after keeping for 7 days (both counts on the 20° plates). The maximum counts of liquefying bacteria were 480,000 in the skin after keeping for 5 days and 2600 in the subcutaneous muscles after keeping for 7 days; this group of bacteria occurred in only one-half of the refrigerated specimens. Bacteria producing gas in glucose broth were found, in the fresh birds, in 3 specimens of the skin, and in 2 specimens of the subcutaneous muscles, and, in birds refrigerated for 5 days, in 2 specimens of the skin and in 2 specimens of the subcutaneous muscles.

In the chickens kept at room temperature, the bacteriological examination was limited to the subcutaneous muscles of the breast and the inner thigh, but included all five groups of bacteria: aerobic plus facultative, anaerobic plus facultative, anaerobic plus facultative resistant to 80° C., liquefying, and fermentative. Usually the counts increased enormously. The highest count of aerobic plus facultative bacteria (20,000,000 per gram) was in the chickens kept for 4 days, the next highest count (6,900,000 per gram) in those kept for 3 days. The anaerobic and facultative bacteria also increased, a count as high as 20,000,000 per gram was obtained in birds kept for 4 days. The anaerobic and facultative bacteria resistant to 80° C. were present in more samples and in larger numbers when the chickens were kept for several days; the number per gram ranged between 0 and 40 in the fresh muscle, and attained a maximum value of 5700 after decomposition for 4 days in the room. The cited counts occurred on plates incubated at 20° C. The number of liquefying bacteria per gram in the chickens kept at room temperature ranged between 0 and 15,000. Bacteria producing gas in glucose broth occurred in 2 specimens from fresh birds and in 2 speci-

TABLE X.—*The Influence of Temperature and Time of Holding upon the Width of Chicken Muscle Cells*

			Roasters																Broilers								
			Fresh	Room			House refrigerator	Chill room			Hard frozen								Fresh	Hard frozen							
											Uneviscerated				Eviscerated					Uneviscerated				Eviscerated			
				2 days	3 days	4 days	4 days	4 days	12 days	18 days	4 mos.	8 mos.	12 mos.	16 mos.	4 mos.	8 mos.	12 mos.			4 mos.	8 mos.	12 mos.	16 mos.	4 mos.	8 mos.	12 mos.	16 mos.
Breast	Number of cells measured *		50	50	50	50	50	50		50	50	50	50	50	50	50	50		50	50	50		50	50	50	50
	Cell widths in micra	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
		0– 9.9																			4						
		10.0–19.9									6	10	10	12	6	16	30			6	26	10		4	34	32	34
		20.0–29.9	22	30	12	4	12	30		42	46	62	66	62	56	68	64	28	54	54	74		60	56	60	62
		30.0–39.9	52	46	36	22	56	58		54	44	26	24	24	36	16	6	68	40	20	10		34	10	8	4
		40.0–49.9	22	22	30	42	30	10		4	4	2		2	2			4			2		2			
		50.0–59.9	2	2	18	20	2	2																		
		60.0–69.9	2			8																				
		70.0–79.9			2	4																				
		80.0–89.9			2																					
Leg	Number of cells measured *		100	50	50	75		50	50	50	50	50	50		50	50	50	75	50	50	50	50	50	50	50	75
	Cell widths in micra	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
		0– 9.9																			2	4		2		
		10.0–19.9	1								6	14	32		12	28	26	16	10	16	18	58	6	14	46	56
		20.0–29.9	33	12	8	8		6	14	22	50	78	58		66	56	72	52	60	74	80	36	50	58	50	40
		30.0–39.9	56	52	34	33		52	68	62	38	6	10		22	16	2	24	26	10		2	38	26	4	4
		40.0–49.9	10	30	42	27		36	14	16	6	2						7	4				6			
		50.0–59.9		6	8	19		6	4																	
		60.0–69.9			8	9												1								
		70.0–79.9				4																				

* The number of cells within each group of 10 micra has been calculated as percentage of the number of cells measured at each period of analysis.

mens from the kept birds: Those producing gas in lactose broth occurred twice in specimens from fresh birds, and four times in specimens from the kept birds.

HISTOLOGICAL CHANGES

During the study of the histological sections of chicken muscle, 4 to 7 micra thick, the width of 2325 individual muscle cells was measured by means of a Zeiss filar micrometer and a Zeiss apochromatic 8 mm. objective, although occasionally a 4 mm. objective was used. The tube length was 160 mm. Each set of lenses was standardized by means of a stage micrometer. The stained longitudinal sections of breast muscle (*Pectoralis major*) and of the group of muscles from the inner thigh (designated leg muscles in the discussion) were used; and only those cells were measured which were characterized by distinct cross markings and parallel edges; all narrow ends and all irregularities were avoided. At least 50 and, at times, as many as 150 individual cells were measured for each type of muscle (breast and leg), at each period and each temperature of holding. The width of each cell was calculated to the nearest tenth of a micron. The cells of each group have been divided into subgroups of 10 micra, or simple multiples thereof; the number of cells in each subgroup has been calculated as percentage of the total number of cells in that entire group; and this percentage has been entered on the table. The minimum and the maximum cell widths in the muscles of fresh chickens were, in micra: broilers, breast 20.9 and 42.2; leg 11.0 and 60.3; roasters, breast 20.2 and 64.8, leg 17.4 and 48.2.

The muscle cells shrunk or decreased in width during storage hard frozen or in the chill room, and became swollen or increased in width during keeping in an iced household refrigerator or at the temperature of the room. These changes become apparent on comparison of the percentage of the cells less than 30 micra in width under specified conditions with the value in fresh birds. These changes in cell width tended somewhat to be progressive, thus the percentage of cells in the leg muscle less than 30 micra in width was 68 in fresh broilers, and 70, 90, 100, and 98 in uneviscerated broilers stored hard frozen for periods of 4, 8, 12, and 16 months, respectively; it was 34 in fresh roasters, and 12, 8, and 8 in roasters kept at the temperature of the room for periods of 2, 3, and 4 days, respectively.

In the chickens which were stored hard frozen, the muscle cells underwent a gradual loss of staining power and also became ruptured. These changes were most marked after storage for one year, and more prominent in the breast muscle than in the leg muscle. The nuclei were more intensely stained, but the cytoplasm was poorly stained. After storage for 12 months, the number of ruptured muscle cells per 100 fields at a magnification of 187 was: in uneviscerated roasters 800, eviscerated roasters 1130, uneviscerated broilers 1000, eviscerated broilers 1200. The cellular contents were exuded into the surrounding areolar tissue.

Degenerative changes also occurred in the blood vessels and the nerves; thus the endothelial lining frequently was torn loose from the muscular coat of the arteries.

In the chickens kept in the mechanically refrigerated chill room, the cells of the leg muscles in the 4 day sample were wider, on the whole, than in fresh roasters. Thereafter these cells showed a progressive shrinkage in width, as did the cells of the breast muscle throughout the experiment. The muscle cells were unevenly stained at the fourth day; ruptured sarcolemmas were present then, and increased in frequency thereafter. The number of ruptured cells in the leg muscles per 100 fields at a magnification of 187 was: Fresh 0, 4 days 131, 12 days 224, 18 days 340. Exudation of the cytoplasm, a deeper staining of the nuclei, and rupture of the endothelial lining of many of the arteries had occurred at the eighteenth day.

In the chickens, which had been kept in an iced, household refrigerator for a period of 4 days, the muscle cells were increased in width; they and the elastic connective tissue appeared somewhat swollen; the sarcolemma was badly ruptured in the majority of the muscle cells; and their cytoplasm was exuding. In these sections, bacteria were not present in the muscle cells, the surrounding loose, areolar connective tissue, or the escaping sarcoplasm.

When chickens were kept at the temperature of the room, at the end of 2 days, the muscle fibers appeared swollen, and their sarcolemma was frequently ruptured. The measurements of cell width showed increases in the breast muscle after the second day, in the leg muscle even on the second day. The staining of the tissue was even on the second day, even but less intense on the third day.

On the third day, the swelling of the muscle fibers had increased considerably, and the number of ruptured fibers had also increased. Cytoplasm was exuding through the ruptured sarcolemma. Bacteria were abundant in the exuded material and within the cell walls.

On the fourth day, the staining of the tissue was less even. Individual muscle cells were distinguished with great difficulty since they were enormously swollen and pressed so closely together. Cells with a ruptured sarcolemma were still more abundant; and the areolar connective tissue usually was filled with the exuded sarcoplasm. Bacteria were present in great numbers within the muscle cells and throughout the masses of exuded sarcoplasm. The nuclei were stained far more faintly than in fresh muscle.

PHYSICAL CHANGES

At the temperature of the chill room, after 14 or even 21 days, a chicken remained fresh and in excellent condition; the bloom was retained; the skin and the muscles had a normal appearance; there was absolutely no odor; and putrefaction was entirely absent. The bird

was edible, had not deteriorated in flavor, and, in fact, had "ripened" to its improvement.

In the house refrigerator, a chicken usually remained in edible condition for at least 4 days; the appearance was good; the muscle firm, and a putrid odor entirely lacking. After even 7 or 8 days, the bird, as a rule, had not spoiled although it had become stale. However, occasionally, toward the end of such a period a green color may develop, and the early stages of putridity appear.

At the temperature of the room, the skin and the superficial muscles became greenish, technically known as "green struck." Pennington and Sherwood (22) found that this typical green color is due to green sulfhemoglobin which is produced in the blood capillaries by the action on their hemoglobin of hydrogen sulfide, a product of bacterial metabolism during intestinal putrefaction. The muscles lost their firmness and became soft; desquamation occurred; a putrid, nauseating odor developed; gas collected in the abdomen, crop, and subcutaneous areolar tissue; and the bird assumed a bloated appearance. These changes were apparent by the second day; by the seventh day, the carcass may have swollen to twice its size. Such chickens are putrid, and are not edible.

When chickens are properly killed and dressed, and enter the freezer in good condition, they may be kept there for a reasonable period of time—from one season of abundant production to the next—without appreciable deterioration. After thawing in dry air, the skin retains its clear fresh color and soft texture. At times, the flesh of the thighs and breast becomes very slightly deeper in color than in fresh poultry, but the change is negligible. The fat deepens slightly in color, and may be characterized by a faintly rancid odor and taste. At about the sixth month of holding, a trained observer notes a slight difference in taste between the flesh of a hard frozen or cold storage chicken and that of a fresh bird. This difference in taste is still slight up to and including nine months of storage, and is scarcely of more than scientific interest. After nine months, the flesh is still wholesome and nutritious, but a distinct loss in flavor has occurred. After chickens have been kept in freezer storage for several years, their fat responds to the test for aldehydes, and compounds of this type possibly are the cause of the rancid flavor (17, 18).

SUMMARY

Data have been presented concerning the gross composition, and the nitrogen partition of the musculature of the common fowl, *Gallus domesticus*, and concerning the constants of its fat, when in the fresh state, and after keeping at certain temperatures for definite periods of time. The physical changes on such keeping have also been described.

No marked differences were found between Plymouth Rock and Leghorn broilers in respect to the gross composition of the meat and the fat constants. In the nitrogen partition of the musculature, Plymouth

Rock broilers consistently had a lower value for the total nitrogen of the aqueous extract.

Broilers contained a slightly lower percentage of water and a slightly higher percentage of protein, in both the light meat and the dark meat, than did roasters. In the nitrogen partition of the musculature, broilers had a higher proteose content. The acid value of the fat tended to be higher in broilers than in roasters.

In both broilers and roasters, the percentage of ether extract usually was higher and the percentage of protein lower in the dark meat than in the light meat. The light meat had a higher value, in both roasters and broilers, for total nitrogen of the aqueous extract, amino acid and basic nitrogen, and peptone nitrogen, and a lower value for proteose nitrogen. The coagulable nitrogen of the aqueous extract tended to be lower in the light meat of broilers and higher in the light meat of roasters.

During storage in the hard frozen state, the musculature suffered a loss of water which tended to be progressively greater as the period of storage lengthened, tended to be greater in the light meat than in the dark meat, and greater in broilers than in roasters. Consequently percentages of the total solids and their components increased. Proteolysis occurred, especially during the last half of the storage period, with the production of amino acids, primarily at the expense of the proteoses and peptones.

In the fat, the iodine number first decreased, then increased. The saponification number and the Hehner number exhibited a marked tendency to change in the same direction at the same time. The acid value tended markedly to increase, usually in a progressive manner.

In the mechanically refrigerated chill room, chickens showed a slight increase in the water content of the musculature, apparently due to the high relative humidity of the environment. Proteolysis was revealed by progressive increases in the amino acid content of both kinds of meat. The acid value of the fat increased progressively.

In an iced refrigerator, both kinds of meat showed a decrease in their content of water and of protein and an increase in their creatinine content. Proteolysis occurred, characterized by an increase in the total nitrogen of the aqueous extract and by the accumulation of amino acids as the end product. The acid value of the fat increased.

In the chickens kept at room temperature, the chief changes in gross composition were a decrease in the protein content of the meat and an increase in its creatinine content. The meat underwent proteolysis, revealed by an increase in the total nitrogen of the aqueous extract, and by a progressive increase in its amino acid content. Progressive increases occurred in the acid value of the fat, and, in 4 days, almost one-fourth of the glycerides had been hydrolyzed.

The proteolysis, as measured by the increase in amino acid and basic nitrogen, during keeping roasters at the temperature of the room for 2 days was in excess of that occurring in fowls kept for periods of 5 to 7 days in an iced refrigerator, or during their storage in a mechanically refrigerated chill room for a period of 14 to 21 days, or in roasters stored hard frozen for 16 months. This proteolysis usually was at the expense of the proteoses and peptones, occasionally at the expense of more complex proteins. It was due to native proteases of the tissues. The infrequent occurrence and low counts of liquefying bacteria excluded them as a prominent factor in the proteolysis.

The deterioration of the fat, as measured by the increase in acid value, in roasters kept in the room for 2 days, was in excess of that in fowls kept in an iced refrigerator for 5 days or in a mechanically refrigerated chill room for 21 days, and of approximately the same magnitude as that in roasters stored hard frozen for 16 months.

Immediately after killing, the superficial and deep muscles, liver, and blood of chickens were bacteriologically sterile. However a general and fairly rapid invasion of the muscles by bacteria then occurred. During freezer storage, bacteria in the muscles and the abdominal wall survived and retained their power to proliferate on nutrient media at more favorable temperatures. Nevertheless, the number of bacteria per gram of muscle tended to decrease during such storage. The bacterial count per gram of tissue increased when chickens were kept in a mechanically refrigerated chill room, in an iced refrigerator, or at room temperature. The increase was most marked at room temperature.

The histological examinations and measurements revealed that the muscle cells shrunk or decreased in width during storage hard frozen or in a mechanically refrigerated chill room, and became swollen or increased in width during keeping in an iced refrigerator or at the temperature of the room. These changes tended somewhat to be progressive. Among the changes observed were alterations in staining power, a ruptured sarcolemma with exudation of the sarcoplasm, and degenerative changes in the blood vessels and nerves. Bacteria were found only in the sections from birds kept at the temperature of the room for 3 or more days.

REFERENCES

(1) PENNINGTON, HEPBURN, ST. JOHN, WITMER, STAFFORD AND BURRELL, *Journal of Biological Chemistry*, Vol. 16, pp. 331–368 (1913–14).

(2) JENKINS, HEPBURN, SWAN, AND SHERWOOD, *Ice and Refrigeration*, Vol. 58, pp. 140–147 (1920).

(3) PENNINGTON, HEPBURN, ST. JOHN AND WITMER, *Journal of Biological Chemistry*, Vol. 29, pp. xxxl–xxxlv (1917).

(4) HEPBURN, *Hahnemannian Monthly*, Vol. 55, pp. 708–713 (1920).

(5) PENNINGTON, *Cold Storage Legislation*. Hearings before the Committee on Agriculture, House of Representatives, Sixty-sixth Congress, First Session, on Cold Storage Legislation, 385–399 (1919).

(6) PENNINGTON, *Foods Held in Cold Storage.* Hearings before the Committee on Manufactures, United States Senate, Sixty-second Congress, on Foods Held in Cold Storage, 57–77 (1911).
(7) PENNINGTON, United States Department of Agriculture Bureau of Chemistry Bulletin No. 115, 57–99 (1908).
(8) HEPBURN, JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 172, pp. 369–398 (1911).
(9) United States Department of Agriculture, Agricultural Statistics 1946, pp. 413, 415, 438
(10) PENNINGTON AND BETTS, United States Department of Agriculture, Bureau of Chemistry Circular No. 61 Revised, 1–11 (1915).
(11) PENNINGTON AND GREENLEE, *Journal American Chemical Society*, Vol. 32, pp. 561–568 (1910).
(12) PENNINGTON AND HEPBURN, *Ibid.*, Vol., 32, pp. 568–572 (1910).
(13) PENNINGTON AND HEPBURN, United States Department of Agriculture, Bureau of Chemistry Circular No. 75, 1–7 (1911).
(14) PENNINGTON AND HEPBURN, *Journal American Chemical Society*, Vol. 34, pp. 210–218. (1912).
(15) PENNINGTON AND HEPBURN, United States Department of Agriculture, Bureau of Chemistry Circular No. 103, 1–3 (1912).
(16) PENNINGTON AND HEPBURN, United States Department of Agriculture, Bureau of Chemistry Circular No. 103, 4–5 (1912).
(17) HEPBURN, United States Department of Agriculture, Bureau of Chemistry Circular No. 75, 8–11 (1911).
(18) HEPBURN, *Journal American Chemical Society*, Vol. 34, pp. 218–222 (1912).
(19) HEPBURN, United States Department of Agriculture, Bureau of Chemistry Circular No. 103, 6–12 (1912).
(20) HEPBURN, *Biochemical Bulletin*, Vol. 4, pp. 136–150 (1915).
(21) HEPBURN, JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 179, pp. 581–585 (1915).
(22) PENNINGTON AND SHERWOOD, *Poultry Science*, Vol. 1, pp. 114–124 (1922).
(23) PENNINGTON, WITMER AND PIERCE, United States Department of Agriculture, Bureau of Chemistry Circular No. 70, 20 (1911).
(24) *Pennsylvania Manual*, Vol. 87, p. 103 (1945).
(25) PENNINGTON, *Premier Congrès International du Froid*, Vol. 2, pp. 216–260 (1908).

Glycerine.—Four booklets, covering the use of U.S.P. glycerine in the fields of foods, drugs and cosmetics, alkyd resins and ester gums, and textiles, and a fifth work which is a general survey of all other glycerine uses, have been published by the Glycerine Producers' Association. They combine basic technical data of concern to chemists, engineers, etc., with interesting facts about usage for the non-technical buyer.

Glycerine has four major properties—as a humectant, a solvent, a sweetener, and an antiseptic, and its hundreds of uses touch nearly every industry. In textiles, glycerine's humectant and plasticizing actions play important roles in applications from sizing to finishing and printing; in the foods industry it is used in an almost endless list of things, ranging from baby foods to nut treating; there are already well over 500 known uses for glycerine in pharmaceuticals and toilet goods; and its chemical structure makes possible a wide variety of modifications of the basic resin.

Included in all of the booklets are tables of specific gravity, viscosity, freezing point, etc. of aqueous glycerine solutions at various concentrations, and a bibliography of references.

The booklets have been prepared with the assistance of technical consultants, and the research laboratories of the Glycerine Producers' Association. Copies can be had free on request to the Glycerine Information Service, Dept. PR, 295 Madison Avenue, New York City 17.

Plastic Photometer.—A 700-lb. plastic sphere that will be used to measure the light output of 8-ft. Slimline fluorescent lamps was recently put into service at the Westinghouse Lamp Division, Bloomfield, N. J. Known as a photometer, the 9-ft. sphere is made of the same resinous material that was used for lifeboats during the war. It was built by Lunn Laminates, Inc., of Glen Cove, N. Y.

Fluorescent lamps to be tested are first warmed to normal operating temperature in a rack adjacent to the photometer. They are then fed mechanically into the sphere to eliminate the possibility of damaging the interior reflecting surface. A light-sensitive photocell in the sphere measures the light output of the lamp; the value is read on an instrument at the operator's table, together with values of wattage, voltage, and current. Carefully controlled laboratory temperature and humidity make possible light-measuring accuracies of more than 99 per cent.

Eleven coats of interior paint, including six top coats of a special chalk-white paint that rubs off if touched, provide ideal reflection conditions. Every three months, the sphere interior must be repainted with five coats of this paint.

New Type Spark-Plug Gives Better Service (*White Metal News Letter*, Vol. XV, No. 1).—Industry now has a new type rust-proof spark-plug which is made of Monel with a nickel adjustable center electrode and a "shatter-proof" ceramic insulator. It has twice the life of the ones previously in use. The manufacturer recommends that they be cleaned every 10,000 miles as compared to the 5,000 miles for the average plug. In many instances this new rustproof plug has run 15,000 to 25,000 miles before receiving attention. It has been put into extensive service in the Middle West. Experience has shown that in using these spark-plugs, motor trucks have been able to save up to 10 per cent in gasoline consumption.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS*

THE OMEGATRON

The omegatron, a recent development at the National Bureau of Standards in the realm of atomic instrumentation, is basically a miniature cyclotron. The omegatron was developed by J. A. Hipple, H. Sommer, and H. A. Thomas, and has already made significant contributions in two fields: First, it makes possible measurement of the numerical value of the faraday with exceedingly high precision. For the first time the faraday is being evaluated directly by physical methods—all previous faraday measurements have been electrochemical. Second, the value of the nuclear magneton may now be determined very precisely, so that the ratio of the mass of the electron to the mass of the proton will be known with greater precision than ever before.

Since the faraday was defined as a unit of quantity of electricity, many attempts have been made over a period of 100 years to determine its precise value, but only now with the development of the omegatron has an independent physical determination become possible. There is a discrepancy between the two best previous determinations—with the iodine voltameter and with the silver voltameter. This inconsistency has been distressing to scientists engaged in revising the tables of atomic constants, since the faraday is a key component of these tables.

In addition to absolute measurements of mass, the omegatron has many other possible uses. For example, its high resolution and extreme sensitivity make it ideal for analysis of gases and vapors, and for the measurement of nuclear packing fractions (the excess of actual mass value over mass number for any isotope) which are very important in atomic physics.

The omegatron operates on the same fundamental principle as a large cyclotron, yet the heart of the instrument is little larger than a package of cigarettes. The instrument now employs a rather bulky electromagnet, but a much smaller permanent magnet would serve as well and make the whole assembly desk-top size.

The functioning of the omegatron can be explained in terms of a simple physical law. If a charged particle is moving in a uniform magnetic field it will trace out a circular path. The particle's angular velocity, ω_c, about the center of the circular path is given by the so-called cyclotron equation $\omega_c = eB/M$, where e/M is the charge-to-mass ratio of the particle, and B is the magnetic flux density. In the cyclotron this property makes it possible to accelerate charged particles to

* Communicated by the Director.

extremely high velocities. In the omegatron, however, it is used to discriminate between particles of different masses: the heavier particles will have a lower angular velocity. Measurement of ω_c with the aid of accurate frequency standards and measurement of B by means of nuclear resonance methods provide an absolute determination of e/M in terms of the magnetic field strength and the cyclotron frequency alone.

In addition to the constant and uniform magnetic field, the omegatron employs a radio-frequency electric field applied at right angles to the magnetic field. When the angular frequency of the electric field is ω, a charged particle will revolve in a plane perpendicular to the magnetic field at an angular velocity of $\frac{1}{2}(\omega + \omega_c)$. If the radio frequency differs from the cyclotron frequency, the radius of the ion path will periodically increase and decrease. The radius of the path traced out by the ion is then

$$R = \frac{K}{\omega - \omega_c} \sin \frac{\omega - \omega_c}{2} t,$$

where K is a constant that depends in part on the strength of the r-f field and t is time. When the two frequencies are close together, the maximum radius of the path will be larger than when they are more widely separated, and when the frequencies are equal (in resonance) the radius of the path will increase steadily and the ion will spiral outward from the center. A collector placed at a fixed distance from the center of rotation of the ions will give maximum ion current at resonance.

Resonance in the omegatron is quite sharp and can be determined very precisely. The degree of sharpness of this resonance condition is described as the "resolution" and is defined as the width of the resonance peak at its base (expressed in cycles per second) divided by the center frequency of the peak. Resolution is proportional to the number of revolutions an ion makes before striking the collector. For greatest resolution, the ions must be held in the omegatron as long as possible. A trapping field produced by a positive potential applied to a set of guard rings retards axial loss of the ions. With the aid of this trapping field, ions are held for more than a millisecond so that they have time to complete thousands of revolutions before being collected.

Resolution increases as the r-f voltage is lowered, but the accompanying decrease in ion current at the collector places a limit on the attainable resolution. The omegatron has yielded resolutions as high as 1/14,000 at unit atomic mass, with strong indications of still higher resolutions to come. The extreme sensitiveness of the omegatron permits operation with very small samples. A wide range of operating pressures is possible; excellent resonance peaks have been obtained at pressures of the order of 10^{-7} millimeters of mercury.

POLARIZED LIGHT SHOWS NATURE OF PLASTIC DEFORMATION IN MONEL METAL

The ability of a metal to deform plastically without breaking enables it to withstand the inevitable misalignments and changing stress conditions that occur in machines and structures. Likewise, the shaping of a metal by rolling, pressing, drawing, or forging is dependent on its ability to deform plastically. A thorough knowledge of the factors involved in the plastic deformation of metals thus becomes highly important in obtaining maximum service from machine parts and other metal products.

Changes in the orientation of the crystals, or grains, that make up the commercial metals are known to play an important part in the deformation process. However, attempts to study grain orientation by the usual X-ray diffraction methods have been rather unsuccessful where only minute areas are involved. An obvious difficulty, for example, has been the identification of the area from which the diffraction pattern was obtained. Recently, D. H. Woodard of the National Bureau of Standards, in the course of a study of plastically deformed Monel metal, developed a technique[1] which uses polarized light to make visible differences in orientation that result from the deformation of a fully annealed specimen. Though use of the technique has thus far been confined to Monel, the method is expected to find application in studies of plastic deformation in other metals.

When Monel is polished and treated with most etchants, it is optically isotropic, reflecting polarized light equally in all directions. However, when specimens were given a light etch (about four seconds) with the Monel Contrast Etch (an aqueous solution of chromic and nitric acids in ammonium chloride), the surface of the metal became optically active. Under these conditions polarized light can be used to detect differences in grain orientation.

Monel that had been annealed so as to give uniform point-to-point orientation within individual grains was viewed microscopically under polarized light with polarizing elements in the incident and reflected beams crossed. The intensity of the reflected light was uniform over each grain. However, when the annealed Monel was deformed before being sectioned and polished, the intensity of the reflected light was no longer uniform over the individual grains. It was thus possible to study visually those regions which had undergone changes in orientation.

Tensile specimens that had been given different amounts of plastic extension were sectioned and polished and used to study the effect of increasing plastic deformation on the changes in orientation within individual crystals. From the irregularity of these changes, it was

[1] For more complete details, see "Stages in the deformation of Monel metal as shown by polarized light," by P. H. WOODARD, *Metals Trans.*, Vol. 185, p. 722 (1949).

evident that directions of flow varied within small areas and that the deformation in individual grains was by no means uniform or regular. Furthermore, the deformation was confined neither to the areas near the grain boundaries nor to the center of the grains but depended upon the orientation of adjacent crystals and the direction of the stresses they imposed.

Thin, straight parallel lines known as "slip lines" are usually visible on polished and etched surfaces of annealed metals after slight deformation. Sometimes these lines are curved on specimens that have been deformed previously. There has been some question as to the interpretation of this curvature. Some investigators have suggested that a group of such curved lines represents a set of crystallographic planes which are bent; others contend that the curves are the traces of several sets of parallel crystallographic planes which remain straight but combine to give the effect of curved lines. Use of polarized light at the Bureau to show differences in orientation along the length of a line indicated that the slip lines were traces of crystallographic planes that had been bent prior to the formation of the slip lines. Some of the differences in orientation observed in individual grains, which were more pronounced after severe plastic deformation, may therefore be interpreted as bending of the crystal lattice. This bending of the crystals during plastic deformation leads to the development of deformation bands. As deformation proceeded, these bands behaved as individual crystals and thus could be considered as fragments of the original crystal.

It was found that the total intensity of the combined reflections from many grains varied as the specimen was rotated with respect to the plane of polarization. Since this integrated intensity increased with greater deformation, it appeared that polarized light might be used to detect preferred orientation resulting from such shaping processes as drawing, rolling, and stamping. Preliminary results indicate that the Bureau's method is more sensitive than X-ray diffraction methods for this purpose. Recently it has been found that other cubic metals, such as copper, aluminum, nickel, and alpha iron, can be made optically active. Thus this new application of polarized light can be used in the study of a number of commercial metals.

THE FRANKLIN INSTITUTE

STATED MONTHLY MEETING, MAY 17, 1950

The May stated meeting of The Franklin Institute was held in the Lecture Hall on Wednesday evening, May 17, 1950, with approximately 250 persons attending.

The President called the meeting to order at 8:15 P.M.; and stated that the minutes of the March meeting, which had been printed in full in the April issue of the JOURNAL, would stand approved in the absence of corrections or additions. There were no corrections or additions, and he announced the minutes approved.

The President summarized the Annual Report of the Board of Managers for 1949 and stated that it would appear complete in an early issue of the JOURNAL. He then recognized the Secretary who reported that Dr. Eugene Paul Wigner had been nominated by the Board of Managers for Honorary Membership in The Franklin Institute, as a recipient designate of the Franklin Medal, and stated the provisions of the By-Laws applicable to his election. The President called for a *viva voce* vote on the nomination and, all votes heard having been for the affirmative, declared Dr. Wigner elected.

The President then recognized Mr. Ralph Kelly, Chairman of the Vermilye Medal Committee of the Board of Managers, who spoke of the outstanding achievements of Mr. J. Howard Pew in the field of Industrial Management and cited him to receive the Vermilye Medal. That medal, and the accompanying citation, were then presented to Mr. Pew by the President, with his congratulations.

Thereafter, the President recited the circumstances underlying the annual Charles Day Lecture, and introduced Mr. Pew as the speaker of the evening.

Mr. Pew talked on "Management and the Free Market" to the great enjoyment of his audience and was tendered a rising vote of thanks as the meeting adjourned.

HENRY B. ALLEN
Secretary

[ED. NOTE: The full report of the Board of Managers and the full proceedings of the Vermilye Medal Presentation, including the text of Mr. Pew's address, will be published in the July issue of the JOURNAL.]

JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in the JOURNAL within the next few months:

BEYER, ROBERT T. AND MING-YI WEI: An Extension of a Theory of Magnetic Amplifiers

THORNTON, WILLIAM M., JR., AND EDWARD S. HAUBER: Zirconium as a Material for Fractional Weights

WALLMAN, HENRY: An Electric Integral-Transform Computer and the Practical Solution of Integral Equations

LAUTERBACH, KENNETH E.: Specific-Surface Determinations of Uranium Dusts by Low-Temperature Adsorption of Ethane

KRZYWOBLOCKI, M. Z.: On the Asymptotic Expansion in Three-Dimensional Compressible Viscous Flow

MERIAM, J. L.: Differential Analyzer Solution for the Stresses in a Rotating Bell-Shaped Shell

MOON, PARRY AND DOMINA EBERLE SPENCER: Interflections in Coupled Enclosures

BORG, S. F.: Additional Interpretations of the Solution of the Straight Beam Differential Equation

AYRE, R. S., L. S. JACOBSEN AND A. PHILLIPS: Steady Forced Vibration of a Non-Conservative System with Variable Mass; a Pumping System

COMMITTEE ON SCIENCE AND THE ARTS

(Abstract of Proceedings of Stated Meeting held Wednesday, May 10, 1950.)

HALL OF THE COMMITTEE,
PHILADELPHIA, MAY 10, 1950.

MR. LEWIS P. TABOR in the Chair.

The following reports were presented for final action:

No. 3211: Klystron—Work of Sigurd and Russell Varian.

This report recommended the award of a John Price Wetherill Medal each to Sigurd F. Varian and Russell H. Varian, both of San Carlos, California, "In recognition of their foresight in anticipating the need for a converter of electromagnetic energy in a hitherto unexplored high frequency region of the spectrum, their energy and technical insight in developing for this purpose, a practical device, the klystron, which has opened up new fields in communications applications and research."

No. 3216: Henderson Medal.

This report recommended the award of the George R. Henderson Medal to Paul Walter Kiefer, of New York, New York, "For his contribution to the development of the modern steam locomotive, resulting in great advance in its design and performance; for his contribution to the development of modern freight and passenger car equipment producing better riding qualities and leading to smoother operation; and for his development and use of methods of analysis and appraisal of the design and utilization of locomotive and car equipment which made possible great improvement in over-all, or system operation of this equipment."

No. 3217: Franklin Medal.

This report recommended the award of the Franklin Medal to Eugene Paul Wigner, of Princeton University, Princeton, New Jersey, "In consideration of his work in the application of Group Theory to Quantum Mechanics and his work on many fundamental problems of Theoretical Physics."

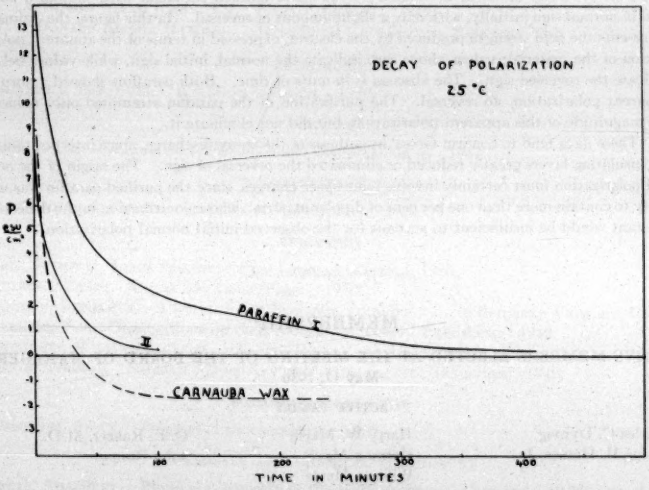
JOHN FRAZER,
Secretary to Committee.

THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

***Abstract of* The Mechanism of Formation of Carnauba Wax Electrets.**[1]—ALAN D. FRANKLIN.[2] An electret is by definition any piece of material exhibiting a permanent or semi-permanent electric field in the space around it. The name was originally chosen by Heaviside because of the analogy to a magnet. The effect was first noticed by Eguchi[3] in carnauba wax, and has since been studied in some detail by many others. The electrets of Eguchi were made by allowing a disk of wax to solidify between two high potential electrodes, although it has been since observed that the wax need not be molten first. By using a movable metal plate upon which the field of the electret could induce an observable charge, it is possible to measure the field surrounding the electret.

[1] Presented before the New York Meeting of the American Physical Society, February, 1950. To be published in *Physical Review*.
[2] Research Engineer (Physical Chemist), The Franklin Institute Laboratories for Research and Development, Philadelphia 3, Pa.
[3] EGUCHI, *Phil. Mag.*, Vol. 49, p. 178 (1925).

The magnitudes of the observed fields are entirely reasonable in terms of the known dielectric constants of the materials. However, the behavior of these fields after the electret is made is quite singular. Immediately after the high field used to make the electret is removed, the electric field in the space around it produced by the electret corresponds roughly to that expected to be if the material possessed a "frozen-in" polarization. The sign of this polarization is that normally induced in a dielectric by the applied external field. As time passes, however, the field produced by the electret decays to zero and reverses sign. In terms of the apparent charges upon wax surfaces, that surface facing the positive electrode during manufacture of the electret has developed a positive apparent charge, while that opposite the negative electrode has developed a negative apparent charge.



What appears to be a reasonable explanation for this behavior has been developed recently by Gross.[4] According to this picture, the applied external field produces two effects during the making of the electret. In the first place, a normal dielectric polarization, due to dipoles or ion space charges, is induced in the wax at higher temperatures and frozen in by cooling before the applied external field is removed. This process gives rise to a negative apparent surface charge upon that surface facing the positive electrode, and *vice versa*, as would normally be expected. But in addition to this, a spray discharge takes place from the electrodes to the wax surfaces, placing there upon a real charge, which may or may not penetrate into the wax from the surface.

The actually observed effects are then due to the sum of these two charge and polarization distributions. Initially, the first predominates, and the over-all sign of the resulting field is that of a normal polarization. But this first, normal dielectric polarization decays rapidly while the spray discharge surface charge is relatively permanent. Thus, the resulting field produced by the electret, normal at first, decays to zero and then reverses sign, until only that due to the remaining spray discharge surface charges is left.

In order to test this theory of the reversal of the field of the electret, the following experi-

[4] GROSS, J., *Chem. Phys.*, Vol. 17, p. 866 (1949).

ment was devised. Disks of wax were precast and were polarized in a field of approximately 2000 volts/cm. at room temperature. Between the wax and the electrodes were placed, however, thin disks of sulfur or Teflon, in order to prevent the spray discharge. In the figure is shown the decay of the field produced by these electrets as a function of time, for an ordinary carnauba wax, for a commercial grade paraffin, and for the same material purified by crystallization from benzene and vacuum distillation. Control experiments conducted without the insulating disks showed measurable currents flowing in the polarizing circuits where these showed none. Further, carnauba wax electrets made under the same conditions as these but without the insulating disks showed only the reversed sign of the field, the reversal taking place in the first few seconds after removal of the applied field. Those made with the insulating disks, on the other hand, as illustrated by the curve marked carnauba wax, showed a large field of normal sign initially, with only a slight amount of reversal. In this figure, the ordinate represents the field strength produced by the electret, expressed in terms of the apparent polarization of the material; values above zero indicate the normal, initial sign, while values below indicate the reversed sign. The abscissa is in units of time. Both paraffins showed a normal apparent polarization, no reversal. The purification of the paraffin attempted only reduced the magnitude of this apparent polarization, but did not eliminate it.

These data tend to confirm Gross' hypothesis of the spray discharge, since interposition of the insulating layers greatly reduced or eliminated the reversal of sign. The origin of the normal polarization must certainly involve ionic space charges, since the purified paraffin was not likely to contain more than one per cent of dipolar material, whose contribution to the dielectric constant would be insufficient to account for the observed initial normal polarization.

MEMBERSHIP

ACTIVE MEMBERS ELECTED AT THE MEETING OF THE BOARD OF MANAGERS May 17, 1950

ACTIVE FAMILY

Charles C. Dybvig	Harry W. Meyle	O. E. Raezer, M.D.
George H. Haines, Jr.	Herman Meyle	John Roman
	William Meyle	

ACTIVE

C. Brinley Bland, M.D.	J. E. Higgins	Humphrey Roper
Charles A. Bockius	Roy K. Jetter	Martha E. Ross
Paul H. Bunten	Julius P. Leof	John H. Slater
Richard H. Chamberlain, M.D.	Albert E. Mace	Francis R. Storey
Philip H. Crist	C. J. Malehorn	Percival Theel
Christopher C. Farrell	Emma Hall Malin	Frank L. Thomson, III
LeRoy A. Grettum	Dudley D. Pendleton, Jr.	S. Murray Viele
Frank C. Hartzell	Frederick W. Purdum	Louis B. Wells
L. A. Hester	Arthur I. Rank	Julius Zied
	Oliver W. Robbins	

ACTIVE NON-RESIDENT

John Fitch

NECROLOGY

Edward M. Biddle '44	Frank J. Briglia, M.D. '45	Bradford Norman '99
	Edward F. Magee '45	

LIBRARY

The Committee on Library desires to add to the collections any technical works that members would wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. The average cost for a print 9 × 14 inches is thirty-five cents.

The Library and reading room are open on Mondays, Tuesdays, Wednesdays and Fridays from 9 A.M. until 5 P.M.; Thursdays from 2 P.M. until 10 P.M.; and Saturdays from 9 A.M. until 12 noon.

RECENT ADDITIONS

AGRICULTURE

BUTLER, EDWIN J. AND JONES, S. J. Plant Pathology. 1949.

FREAR, DONALD ELISHA HARDING. Agricultural Chemistry; a Reference Text. Volume 1. 1950.

ASTRONOMY

VELIKOVSKY, IMMANUEL. Worlds in Collision. 1950.

AVIATION

BLACK, J. An Introduction to Aerodynamic Compressibility. 1947.

BIBLIOGRAPHY

ADAMS, DOUGLAS PAYNE. An Index to Nomograms. 1950.

BIOGRAPHY

DUBOS, RENE J. Louis Pasteur; a Free Lance of Science. 1950.

EINSTEIN, ALBERT. Out of My Later Years. 1950.

FRANKLIN, BENJAMIN. A Letter From Benjamin Franklin . . . to Benjamin Vaughan, Containing Some Observations on the Prodigal Practices of Publishers. 1949.

HUMPHREYS, WILLIAM JACKSON. Of Me—W. J. Humphreys. 1947.

MARTIN, THOMAS. Faraday's Discovery of Electro-magnetic Induction. 1949.

BIOLOGICAL CHEMISTRY

HAUROWITZ, FELIX. Progress in Biochemistry. 1950.

CHEMISTRY AND CHEMICAL TECHNOLOGY

FARKAS, ADALBERT. Physical Chemistry of the Hydrocarbons. Volume 1. 1950.

GOMBAS, P. Die Statistische Theorie des Atoms und Ihre Angewendungen. 1949.

HOUWINK, R., Ed. Elastomers and Plastomers; Their Chemistry, Physics and Technology. Volume 1. 1950.

KARRER, PAUL. Organic Chemistry. Edition 4. 1950.

LAWRENCE, CARL A. Surface Active Quaternary Ammonium Germicides. 1950.

MACHU, WILLI. Chemie und Chemische Technologie. 1949.

SOODAK, HARRY AND CAMPBELL, EDWARD C. Elementary Pile Theory. 1950.

SULLIVAN, WILLIAM H. Trilinear Chart of Nuclear Species. 1949.

CIVIL ENGINEERING

HAYDON, ARTHUR G. AND BARRON, MAURICE. The Rigid Frame Bridge. Edition 3. 1950.

ELECTRICITY AND ELECTRICAL ENGINEERING

HORWOOD, WILLIAM LAURIE. Electrical Technology. Edition 2. 1948.

TROPPER, H. Electric Circuit Theory. 1949.

ELECTRONICS

KIVER, MILTON S. Television Simplified. Edition 3. 1950.

ENGINEERING

JUDGE, ARTHUR W. Engineering Precision Measurements. Edition 2. 1950.
PHYSICAL SOCIETY OF LONDON. Report of a Conference on Strength of Solids. 1948.

GENERAL

KANE, JOSEPH NATHAN. Famous First Facts. Edition 2. 1950.

GEOLOGY

FOX, CYRIL S. The Geology of Water Supply. 1949.
JAGGER, THOMAS AUGUSTUS. Volcanoes Declare War. 1945.

MANUFACTURE

CRAINE, J. H. Ship Modelling Hints and Tips. 1948.
WOODROFFE, DAVID, ED. Standard Handbook of Industrial Leathers. 1949.

MARINE ENGINEERING

MACKAY, JOHN SETON. The Analysis of Marine Steam Indicator Diagrams. 1949.

MATHEMATICS

MOOD, ALEXANDER MCFARLANE. Introduction to Theory of Statistics. 1950.
MOREY, LLOYD. University and College Accounting. 1930.

MECHANICAL ENGINEERING

KERSEY, A. T. J., ED. Internal Combustion Engineering. 1949.

METALLURGY

ASSOCIATION OF LIGHT ALLOY REFINERS. COMMITTEE OF CHEMISTS. Modern Methods for the Analysis of Aluminum Alloys. 1949.

PHARMACY AND PUBLIC HEALTH

ELKINS, HERVEY B. The Chemistry of Industrial Toxicology. 1950.

PHOTOGRAPHY

JUDGE, ARTHUR W. Spectroscopic Photography. Edition 3. 1950.

PHYSICS

ANGOT, ANDRE. Complements de Mathematiques a l'Usage des Ingenieurs de l'Electrotechnique et des Telecommunications. 1949.
CATCHPOOL, EDMUND AND SATTERLY, J. Textbook of Sound. Edition 7. 1949.
DARMOIS, EUGENE. Vibrations Acoustique. 1948.
JELLINIK, KARL. Weltsystem, Weltather und die Relativitats Theorie. 1949.
JOHNSON, RAYNOR C. An Introduction to Molecular Spectra. 1949.
KEMBLE, EDWIN CRAWFORD. The Fundamental Principles of Quantum Mechanics. 1937.
LEFACHETZ, SOLOMON, ED. Contributions to the Theory of Nonlinear Oscillations. 1950.
MANDELKER, JAKOB. Principles of a New Energy Mechanics. 1949.
MILNE-THOMSON, LOUIS MELVILLE. Theoretical Hydrodynamics. Edition 2. 1950.
RIENER, MARKUS. Twelve Lectures on Theoretical Rheology. 1949.
SCHMIDT, ERNST. Thermodynamics. 1949.
STUBBINGS, GEORGE WILFRED. Dimensions in Engineering Theory. 1948.

PSYCHOLOGY

CHAPANIS, ALPHONSE; GARNER, WENDELL RICHARD AND MORGAN, CLIFFORD THOMAS. Applied Experimental Psychology; Human Factors in Engineering Design. 1949.

RADIO

KAUFFMAN, MILTON. Radio Operator's License Q & A Manual. 1949.
MOULIN, ERIC BALLIOL. Radio Aerials. 1949.
MOXON, L. A. Recent Advances in Radio Receivers. 1949.

SANITARY ENGINEERING

HARDENBERGH, WILLIAM A. Sewerage and Sewage Treatment. Edition 3. 1950.

SCIENCE

MCKEEHAN, LOUIS W. Yale Science, the First Hundred Years, 1701–1801. 1947.

MEES, CHARLES EDWARD KENNETH AND LEERMAKERS, JOHN ANDREWS. The Organization of Industrial Scientific Research. Edition 2. 1950.

TAYLOR, FRANK SHERWOOD. Science, Past and Present. 1949.

MUSEUM

Some three centuries ago Francis Bacon expressed the opinion that youth was best fitted for new projects. Today when we see young people absorbed over a new airplane we realize that the opinion is still true. Aviation is the newest form of transportation and it lures youth as the apple lured Eve. Yet few young people can hope to handle an airplane until they have spent tedious hours learning the fundamentals of flight and the intricacies of the internal combustion engine.

It was to meet just such a contingency that The Franklin Institute Museum was established. It was not sufficient that visitors should be able to look at and admire from a distance the various specimens of airplanes that were shown in the Aviation Section. A means had to be devised which would enable the visitors to get the "feel" of flying, to experience the motions of an airplane in flight.

The means lay at hand in the Link Trainer, a device for instructing pilots to fly by instruments. This highly ingenious mechanism is based upon a series of bellows which causes the plane to pitch and roll and drift as it does in actual flight. The trainer is equipped with the necessary controls to keep the plane on an even keel and the essential instruments for navigation. Seated in the pilot's seat, the visitor to the Museum can experience all the sensations of flying without leaving the ground while he performs the pilot's functions without fear of crashing. Although visibility and wind conditions are normally ideal in these surroundings, rough and bumpy weather can be simulated by the turn of a switch.

Instruction is graduated. For the visitor who has no flying sense and is without any experience, there is the junior trainer, which is not very sensitive. This is the instrument upon which young people get enough knowledge of control to graduate to the more sensitive trainer which is much closer to actual conditions. Then for the more expert there is a third trainer in which the visitor can acquire mastery over the finesse required to take off from the deck of a carrier, circle around in the air, and then to set the plane down safely.

Thus the Museum ministers to the joys of flying without risk of broken bones. The provision of these facilities is symbolic of the intimate co-operation the Museum must receive if it is to discharge the obligations it has adopted for instructing young and old, rich and poor in the progress of science and its implications upon our daily lives. The Special Services Center, United States Navy, provided the device for learning take-off and landing, and Esso Standard Oil Company provided and maintains the two others.

An interesting competition is conducted on the Link Trainer. On Saturday afternoons elimination tests are run off to select the young competitors (between 15 and 20 years of age) who, on the last Saturday of each month compete for the prizes. These consist of miniature silver wings (the gift of Mr. Laurence Sharpless) and an hour of actual flight from a nearby airport.

Many and many a grown man eagerly clambers into No. 60,000, the giant locomotive on the Ground Floor, to realize a lifetime's ambition to drive a locomotive. The Museum offers its visitors the unrivalled opportunity of supplementing this experience by piloting man's newest device for conquering space and time. We urge readers to be up to date, to come into the Museum and enjoy the experience. There are no age limits if the visitor's legs are long enough to reach the controls.

BOOK REVIEWS

OUT OF MY LATER YEARS, by Albert Einstein. 282 pages, illustrations, port., 14 × 24 cm. New York, Philosophical Library, 1950. Price, $4.75.

In some sixty essays, originally prepared or delivered since 1934 when his first anthology "The World as I See It" appeared, Dr. Einstein presents thoughts on science and life. The book cannot but appeal to anyone interested in the mind and the spirit of man. The reader will inevitably acquire a deeper understanding of modern science and scientific philosophy, for Einstein must be numbered among the few lucid exponents of his own theory of relativity and the attendant new philosophies and attitudes of science.

In nearly every essay, Einstein the man, the human being, is as apparent as Einstein the scientist. Occasionally the faith and humility of the scientist is temporarily obscured by biting irony when it is forced on the attention that "Reason is weak when measured against its never-ending task. Weak, indeed, compared with the follies and passions of mankind, which, we must admit, almost entirely control our human destinies, in great things and small." (See for example "Message for Posterity.") But, on the other hand, "Science can only be created by those who are thoroughly imbued with the aspiration towards truth and understanding. This source of feeling, however, springs from the sphere of religion. To this there also belongs the faith in the possibility that the regulations valid for the world of existence are rational, that is, comprehensible to reason. I cannot conceive of a genuine scientist without that profound faith. The situation may be expressed by an image: Science without religion is lame, religion without science is blind."

The essays are grouped under "Convictions and Beliefs," "Science," "Public Affairs," "Science and Life," "Personalities," and "My People." A reading of the collection produces the conviction that the author should be included with Max Planck, of whom Einstein says in memoriam: "A man to whom it has been given to bless the world with a great creative idea has no need for the praise of posterity. His very achievement has already conferred a higher boon upon him."

C. T. CHASE

THEORETICAL HYDRODYNAMICS, by L. M. Milne-Thomson. Second edition, 600 pages, illustrations, 16 × 24 cm. New York, The Macmillan Co., 1950. Price, $8.50.

Theoretical Hydrodynamics is a very thorough and clear introduction into the mathematical theory of fluid motion, applicable to hydrodynamics and aerodynamics. The book differs from the traditional treatment of hydrodynamics by presenting the subject matter through the use of vector method and the complex variable, which provides a physical concept of the subject better than that supplied by particular coordinate systems. Of course, such methods require a knowledge of mathematics beyond the calculus, but the author has conveniently included chapters on vector analysis and the complex variable to aid those unfamiliar with advanced mathematics.

Theoretical Hydrodynamics approaches Horace Lamb's classical *Hydrodynamics* in its mathematical treatment of the subject. Commencing with an introductory chapter on Daniel Bernoulli's theorem and one on the vector analysis peculiar to fluid motion, with a later chapter on the complex variable, the author, in separate chapters, explores the equations of motion applied to moving fluids, two-dimensional motion, streaming motions, aerofoils, sources and sinks, moving cylinders, jets and currents, Helmholtz motions (cavitation), rectilinear vortices, waves, the movement of spheres and ellipsoids (spherical and ellipsoidal harmonics), solid moving through a liquid, vortex motion, viscosity, and subsonic and supersonic flow. Proofs of such theorems as those of Bernoulli, Torricelli, Stokes, Gauss, Green, Euler, Schwarz and Christoffel, Kutta and Jankowski, Logally and Kelvin's minimum energy theorem are presented. Because the study of theoretical hydrodynamics is based upon an ideal, inviscid fluid, rendering it susceptible to exact mathematical treatment, the inference should not be made that

the subject has no practical application. As the author discloses, the theory, in certain cases, predicts not only qualitatively but quantitatively the behavior of actual fluids.

To make the subject more easily understood, many diagrams—over 350—are provided. And at the end of each of the twenty chapters numerous examples, illustrating the preceding theory, are presented.

For those who have the first edition of *Theoretical Hydrodynamics*, the present second edition differs from the first, apart from incidental rearrangements and improved presentation: by the introduction of the circle theorem which enables the determination of the disturbance of a given two-dimensional flow by a circular cylinder without calculation; by the corresponding theorem for a sphere; and by the addition of a chapter on the flow of compressible fluids.

E. W. HAMMER, JR.

THE ORGANIZATION OF INDUSTRIAL SCIENTIFIC RESEARCH, by C. E. Kenneth Mees and John A. Leermakers. Second edition, 383 pages, charts, 16 × 23 cm. New York, McGraw-Hill Book Co., Inc., 1950. Price, $5.00.

The authors have divided this book into three parts. Part 1, dealing with the general principles of research, covers very well the background and growth of scientific research organizations. They stress the value of complete freedom of thought and experiment when the results to be expected are completely unknown, and conclude that application of science can be directed to produce results of value. They outline the growth of scientific organizations in both the United States and foreign countries.

In Part 2 of this volume, the authors discuss the agencies for the conduct of research, breaking them down into three groups: government laboratories, associations for industrial research, and technological research institutes. They pick out several outstanding examples of each type of laboratory, and also cover these laboratories not only in the United States but in Great Britain, the British Commonwealth, Russia, and Germany.

Part 3 of this book deals with the organization of industrial laboratories and the authors cover this field from the position of the laboratory in an owning corporation or company setup through the internal organization of the laboratories themselves, including the selection of laboratory programs, the direction research is to take, the problems involved in the transposition of research to production, reports, patents, publications, and library services, as actually handled in various company setups. They also go into the financial administration of the laboratories, personnel, salary administration, supplies and services, the design of a laboratory for a specific industry, and even suggest the design of laboratories and laboratory buildings. They cite actual practices from various companies which were studied.

The authors have done a very fine job of tracing the development of industrial research laboratories and of presenting official information that should be valuable to management considering the formation of a research program for its own company and to those officials of established laboratories who may wish to draw comparisons with practices and policies of similar organizations. All the points are stressed according to the size of the organization. This text is not to be considered a handbook from which all the answers to setting up a research organization can be derived for a particular company, but it contains information from which comparisons can be drawn between the text and the particular size and type of the company which is striving to initiate a research program.

P. F. SUFFREDINI

AIRPLANE PERFORMANCE, STABILITY AND CONTROL, by Courtland D. Perkins and Robert E. Hage. 493 pages, illustrations, 15 × 24 cm. New York, John Wiley & Sons, Inc., 1949. Price, $7.00.

The preface states the following purpose: "To present those elements of applied aerodynamics that bear directly on the problem of airplane design." To this reviewer's knowledge, this is the first book on the general subject of aerodynamics to contain readily usable information on the modern problems of aircraft propulsion, performance, stability and control. It has been written from the standpoint of the design engineer and should be extremely useful in his daily work, since the authors have filled comprehensively the oft-forgotten gap between the study of fundamentals and theory and their application to design.

The book is divided into two major parts. The first part discusses the classical performance and aerodynamic problems of airplane design and the second the art of designing the airplane for acceptable stability and control qualities, better known as flying qualities.

The first major part is subdivided into three chapters, namely, Drag Estimation, Propulsion, and Airplane Performance. The first chapter contains a summary of basic aerodynamics for estimating airplane drag for subsonic, transonic, and supersonic speeds. The second chapter presents concise, up-to-date material on propulsion characteristics of the reciprocating engine, turbine, propellor, turbojet, ramjet and rocket. The third chapter covers the classical performance problem and special problems including range, endurance, take-off, landing, climb, turning, etc.

The second major part is subdivided into seven chapters, namely, Static Longitudinal Stability and Control Stick—Fixed, Static Longitudinal Stability and Control Stick—Free, Maneuvering Flight, Directional Stability and Control, Dihedral Effect and Lateral Control, Longitudinal Dynamics, and Lateral Dynamics. These titles by themselves are considered self-explanatory by this reviewer; however, the method of presentation, the complete modern coverage of the subjects and the discussion of the inter-relations among them are noteworthy of special mention and should be of considerable value to the advanced student and practicing engineer alike. It contains a remarkably complete analysis of the many problems of subsonic stability and control, and the authors have carefully screened the voluminous publications on the subject by presenting a list of suggested references, including technical reports and papers, at the end of each chapter. The authors rightfully have omitted the treatment of transonic and supersonic stability and control as premature.

A minor point of criticism is worth mentioning, inasmuch as it seems to be a common shortcoming in this and many other recent publications. It is the lack of definition, lack of standardization and duplicate meanings of the many symbols used. As examples, both u and v are used to define velocity along the x-axis, both P and q are mentioned as dynamic pressure, and in several cases no definitions could be found for other symbols. Summarizing, however, this book is a welcome addition to the growing list of publications in the rapidly-expanding field of the aeronautical sciences, especially so since it is a "first" on the complex subject of the handling qualities of the airplane.

SAMUEL M. BERKOWITZ

ACOUSTICAL DESIGNING IN ARCHITECTURE, by Vern O. Knudsen and Cyril M. Harris. 457 pages, illustrations, 14 × 22 cm. New York, John Wiley & Sons, Inc., 1950. Price, $7.50.

The subject matter of this book is rather completely described by the title. The authors, both physicists of high repute in the field of acoustics, have written, in this volume, a practical textbook for architects and engineers who may be faced continually with design problems in architectural acoustics. An understanding and application of the technological principles of architectural acoustics are necessary prerequisites for any building planner who is faced with controlling or directing sound.

The twenty chapters in the text are roughly divided into two parts: a consideration of the general principles and procedures which form a basis for good acoustical designing of all types of buildings; and a description of specific applications of these principles and procedures.

While non-mathematical in nature, the text describes in a very clear style the fundamental properties of sound and hearing. Illustrative problems requiring the construction and use of loudness calculations for typical room noise help develop the essential points. These are later amplified in chapters devoted to the principles of room acoustics and the acoustical design of rooms consistent with the limitations established by desired reverberation time, intelligibility, and noise control. Basic physics is followed by chapters devoted to the descriptions and fields of application of the currently used sound absorptive materials and methods of construction. The newest items are discussed aided by many sketches, charts and graphs.

The six chapters devoted to specific design principles and practical suggestions are concerned with: auditoriums for legitimate, motion picture and "little" theaters, and school and

civic auditoriums; school buildings, including planning of classrooms, lecture rooms, music, and miscellaneous rooms; commercial and public buildings, where the major problems are with the exclusion of external noise and the suppression of noise generated within the buildings; houses, apartments, and hotels; church buildings; and radio broadcasting, television, and sound recording studios.

The practicing architect or architectural student may very well wish to refer to this volume as a handbook for acoustical design, especially since many examples of good design are worked out.

S. CHARP

FUNDAMENTALS IN THE PRODUCTION AND DESIGN OF CASTINGS, by Clarence T. Marek. 383 pages, illustrations, 14 × 22 cm. New York, John Wiley & Sons, Inc., 1950. Price, $4.00.

The underlying reason for writing *Fundamentals in the Production and Design of Castings* is not new; any competent engineer realizes the prime importance of designing a product that is both functional and economical. A designer who continually ignores this fundamental concept does not survive in a competitive economy. Most manufacturers are only too well aware of this. However, this book on castings is obviously addressed to those unfamiliar with the highly competitive business world—to college students. The questions following each chapter can only be for such neophyte engineers. For such a group and to those who know nothing about castings, the book is informative. Writing in a very simple and easily understood style, Associate Professor Marek (of Purdue University) describes the various phases of the casting industry quite thoroughly.

Briefly, casting is the pouring of a molten metal into a mold of the desired form. After the metal solidifies, the mold is removed. Numerous methods are used to make the molds; all are discussed in the first six chapters on casting processes, green sand molding, foundry sands and sand control, patterns and related equipment, cores and their applications, and foundry production equipment. Materials handling in the modern casting industry is described in a chapter on productive planning, where it is disclosed how production has greatly improved due to proper arrangement of storage space and equipment and proper mechanical equipment for moving materials. A simplified background in the principles of metallurgy and the equipment used in the production of cast metals is given in chapters on the physical and metallurgical properties of cast metals, properties and uses of ferrous and non-ferrous cast metals, and the melting of cast metals. Such methods of inspecting castings for defects as visual, sound, impact and radiographic, are explained in the chapter on cleaning and inspection. Economical casting design is discussed in the chapter on design for economical molding. In the concluding chapter on design to eliminate defects, some basic and rather elementary principles are presented to illustrate how many casting defects can be avoided by proper design. An appendix contains descriptions for sand testing and control procedure.

E. W. HAMMER, JR.

OUTLINE HISTORY OF TRANSATLANTIC STEAM NAVIGATION, by H. Philip Spratt. 60 pages, plates, 15 × 24 cm. London, His Majesty's Stationary Office, 1950. Price, 2 s. 0 d.

The story of the sea has many romances but it also has an interest altogether apart from flights of fancy or epic adventure. This additional interest rejoices the heart of the engineer, for it deals with man's effort to develop the steam engine so that it might be applied to the conquest of the ocean. The history of this effort is epitomized in the story of the Transatlantic ferry and Mr. Spratt, Deputy Keeper of the Science Museum in London, has condensed it into a desirable little volume.

Dividing the vessels into three broad classes—paddle, screw, and turbine driven, the author traces the progress from wood to iron and from iron to steel ships. By selecting fifty-five vessels and furnishing adequate details concerning their ownership, construction, engines, accommodation, etc., he contrives to provide a satisfactory picture of the progress which has been made since the "Savannah," with an auxiliary engine, made the first ocean crossing in which steam propulsion played a part. Obviously no haphazard choice could have served this pur-

pose, but Mr. Spratt has chosen his examples with care, and the picture he presents could hardly be improved upon within the same compass.

The volume is slight in bulk because unessentials have been rigorously pruned, but it contains a surprising amount of just the right kind of information to tell the story of progress made in engineering efficiency and improved passenger comfort and safety. It is an excellent handy reference book for everyone interested in steam navigation, and forms a worthy addition to the "Special Publications" of the Science Museum, which have an established reputation for scholarship and authority.

There is a uniform arrangement of the details given upon each ship which facilitates the search for a particular item of information. The illustrations are from photographs of prints and models on display in the Science Museum.

T. C.

AN INTRODUCTION TO LUMINESCENCE OF SOLIDS, by Humboldt W. Leverenz. 569 pages, charts, 15 × 24 cm. New York, John Wiley & Sons, Inc., 1950. Price, $12.00.

In this book the author, who is director of one of America's foremost phosphor research groups at R. C. A. Laboratories in Princeton, has attempted to present the basic facts and theories extant today concerning luminescent solids (phosphors). The material covers all the available literature on the subject as well as his own research and experience, and presents over 700 primary references.

Tremendous interest in phosphors is, essentially, almost completely indebted to their indispensability in "fluorescent" (actually "phosphorescent") lighting, cathode ray tubes (television, oscilloscopes, etc.) and other commercial and military applications. As in all research, however, the most efficient method of attaining material results is the inexorable pursuit of the fundamental properties of the phenomena concerned, a fact well illustrated by this book.

The first few chapters of the book present, quite briefly and without allusion to phosphors, general fundamental concepts of matter, the understanding of which is necessary to comprehension of the theory of phosphors which follows. It is interesting to note that, at this point in the book, explicit directions are given to illustrate the actual laboratory synthesis of ten or so phosphors. The book continues with a discussion of crystalline constitution and energy levels, followed by a chapter entitled "Luminescence of Phosphors." Here, as in many other sections of the book, the resolution of subjects is not as clean-cut as a phosphor-neophyte, at least, might wish.

The properties and mechanisms of radiation emissions are considered thoroughly, and admirably illustrated with as many as three different types of energy-level transition diagrams. Where possible, the correlation of phosphor constitution with decay (and other properties) is considered. Phosphor efficiencies are discussed, and as functions of structure, excitation, and other factors. Other properties, assumedly not discussed elsewhere in the book, are taken up in a chapter entitled "General Properties." The remainder of the book is devoted to a careful discussion of the practical applications or uses of phosphors. The author closes with the significant reminder that luminescence is, most important of all, a very sensitive indicator of fundamental changes undergone by solids, and that contributions to our knowledge thusly obtained may some day overshadow the material uses now existent.

ALBERT L. MYERSON

ENGINEERING STRUCTURES, Colston papers based on a Symposium promoted by the Colston Research Society in September 1949. 260 pages, illustrations, plates, 18 × 25 cm. New York, Academic Press, 1949. Price, $4.00.

Engineering Structures contains the papers presented at the Symposium on Engineering Structures held, in September 1949, at the University of Bristol under the auspices of the Colston Research Society. With several exceptions, the papers concern current research investigations in connection with such various engineering structures as bridges, buildings, aircraft and ships.

Sir Richard Southwell introduces the symposium with a discussion of current trends in structural research. In the course of this refreshing and philosophical discussion, Sir Richard

stresses the importance of the comprehensive outlook, deploring the compartmentation of the various fields of engineering. His remarks on the value of structural research, "Rayleigh's principle," Castigliano's Method of Least Work and the plastic straining of structures are very interesting and instructive.

The remaining fourteen papers comprising this informative symposium are generally theoretical and are based substantially on experiment. The papers range from the microscopic to the macroscopic, from the shortening effect of a strut or beam due to torsion to the excellent review of the listing of structures. Some, like the number of waves in a tension field beam and the shortening effect due to torsion, are almost solely of academic interest; while others, like the investigation on aluminum alloy rivets and the carrying capacity of simply supported mild steel beams, are of sound practical value. Within these extremes are papers on such subjects as laterally loaded channel beams, the flexure of rectangular box girders of thin steel plating, the plastic deformation of rectangular plates, the dynamic criteria of buckling, the effect of variable repeated loads in the plastic theory of structure, the effective stiffness of stringers to locally applied loads, performance of compression plates as parts of structural members, the effect of shrinkage on the deformation of concrete under sustained loads and the design of structures on the basis of assumed deformations. Each paper contains references and a discussion by those attending the meeting, which included the authors (from the United States, Sweden, and the Netherlands as well as from England) of the various papers and other internationally known men in the field of engineering structures.

Generally, the papers in the symposium add significantly to the present literature on engineering structures, and, while some may seem to treat of rather unimportant aspects of the field, in the comprehensive view of the theory of structures, all have some value.

E. W. HAMMER, JR.

METHUEN'S MONOGRAPHS ON PHYSICAL SUBJECTS. Illustrations, 11 × 17 cm. London, Methuen & Co. Distributed in U. S. by John Wiley & Sons, Inc., New York.

This series is intended to supply readers of average scientific attainment with a compact statement of the modern position in each subject. Thirteen of the sixteen titles are here reviewed briefly for JOURNAL readers.

Physical Constants, by W. H. J. Childs. 77 pages. 1949. Price, $1.25.

In addition to the contents implied by its title, this small volume contains a number of short mathematical tables: trigonometric functions, common logarithms, etc. Depending on one's predilections, the fact that the C.G.S. system is used throughout may be considered a limitation. The author has not carried out his laudable ambition to keep the successive editions up to date, the last revision having taken place evidently in pre-atomic 1945.

FRANK T. INNES

Fundamentals of Discharge Tube Circuits, by V. J. Francis. 134 pages. 1948. Price, $1.50.

This book deals with the class of discharge tubes employed for lighting purposes, i.e.—fluorescent, sodium, mercury vapor, and neon lamps. The discharge tube as a circuit element is shown to be a complicated non-linear device which makes an analytical treatment in circuit analysis practically impossible. The author presents a semi-empirical method based on the volt-ampere dynamic characteristic of the discharge tube which facilitates the handling of certain problems. The subject of arc initiation and stabilization is fully discussed. The last chapter contains typical circuits for various discharge lamps.

I. GLASSMAN

Low Temperature Physics, by L. C. Jackson. 130 pages. 1948. Price, $1.50.

This interesting monograph describes the methods used to produce low temperatures and make physical measurements near absolute zero. The mathematical theory relating temperatures to gas pressures, specific heat, electrical conductivity and magnetism is of interest to scientists and physicists. Because of the strange and unusual behavior of substances at temperatures near the absolute zero point, many readers will find the book of popular interest if

they skip the equations. At −271°C., liquid helium II is a superfluid which runs uphill to seek a lower level. Some pure metals become super conductors with zero resistance. Theories explaining these and many other effects are outlined. Methods for producing temperatures within 1/1,000 degree centigrade of absolute zero are explained and possible methods for producing even lower temperatures are proposed.

The text is excellent for a basic coverage of the subject and further details can be obtained from the bibliography.

E. A. MECHLER

An Introduction to the Laplace Transformation, by J. C. Jaeger. 132 pages. 1949. Price, $1.50.

This book contains the substance of a series of lectures delivered to a group of engineers and physicists at Sydney in 1944. The purpose of the lectures and the book was to meet the demand for a knowledge of modern operational methods as applied to transient problems. The treatment is not for the mathematical sophisticate, but rather for the man whose training has not gone beyond the calculus. The book concentrates on developing the reader's manipulative skills by containing little theory but many illustrative practical problems from circuit theory. All in all this is an excellent practical introduction to the use of the Laplace Transform.

EZRA KRENDEL

Dipole Moments, by R. J. W. Le Fevre. 117 pages. 1948. Price, $1.25.

Although this book is labelled a second edition of the earlier one published in 1938, very little new material has been added. This reviewer could find no reference to material more recent than 1939. The book is, therefore, a brief review of the use of dipole moments as of 1938–1939. The Debye equations and concept of orientation polarization are set forth, and some of the methods for the measurement of dielectric constants and calculation of dipole moments. A discussion of the effects of solvent upon the solute dipole moment is given. The last half of the book is given over to the application of dipole moments to problems in molecular structure. A table of dipole moments, taken mostly from the table given in a supplement to the Transactions of Faraday Society, Vol. 30, 1934, is included.

A. D. FRANKLIN

The Cyclotron, by W. B. Mann. 92 pages. 1948. Price, $1.25.

This small monograph describes in an elementary manner, the fundamentals of the theory and construction of the cyclotron. A brief discussion of some of its applications is also included.

The book consists of six chapters, the first of which is an introduction. The second chapter, entitled "Magnetic Resonance Acceleration" is a discussion of the theory involved in the acceleration of charged particles by the use of combined magnetic and electric fields.

The next three chapters deal with the actual construction and operation of the cyclotron. The vacuum chamber, the cyclotron magnet, the high frequency supply for the dees and the ion source are described. There is also a discussion of the adjustments necessary for the successful operation of the cyclotron.

The last chapter describes several transmutations and nuclear reactions which can be produced with the aid of the cyclotron. There is also a brief discussion of radioactive tracer techniques.

Although this is the third edition of the book and is dated 1948, the most recent instrument mentioned is the 60 inch Berkeley cyclotron, which was put into operation about 1939. Since then much progress has been made. The latest reference given in the bibliography is dated 1939. The book is well written and easily read, but is of limited value since the more recent research in this field has been omitted.

M. D. EARLE

Cosmological Theory, by G. C. McVittie. 103 pages. 1949. Price, $1.50.

Cosmological Theory is defined as the branch of physics dealing with the structure of the whole physical universe, regarded as a single system. Professor McVittie's book contains a discussion of the state of this theory at about 1937. A description of some of the observational

data available to the physicist is given, including measurements of nebular distances, distributions and masses of nebulae in space, the red shift and the "recession" of the nebulae. As a basis for the theories to follow, an outline of tensor calculus and the generalized differential geometry of Riemannian spaces is given. The principles of general relativity are set forth and are used to derive the theories of the expanding universe. The kinematic theory of E. A. Milne is also described and compared to those of general relativity.

The language is, of course, essentially mathematical, but the fundamentals are laid quite well in the early chapters, so that the treatment as a whole is clear. The book suffers somewhat from the lack of revision since the first edition in 1937, because the important recent work, notably of Schrodinger and Einstein, on deriving gravitational theories from the more general relativistic theories is missing.

A. D. FRANKLIN

The Physical Principles of Wireless, by J. A. Ratcliffe. 110 pages. Price, $1.25.

Here, in a brief 108 pages, Mr. Ratcliffe attempts to present the underlying principle of electronics. For the amount of space allotted to the subject, the author does quite well. From the foreword it is gathered that the book is intended to provide a source of easily understood material for the reader who has had practical experience with radio as a hobby and who wishes to broaden his theoretical background. When looked at from this viewpoint, it can be said that the book fulfills its purpose admirably. While this book will probably not find a place in the reference library of the electronics engineer, it will undoubtedly be welcomed by those who are looking for a concise descriptive explanation of the fundamentals of operation of vacuum tubes and their associated circuits and radio transmitters and receivers.

R. S. GRUBMEYER

Magnetism, by E. C. Stoner. 136 pages. 1948. Price, $1.25.

This book describes briefly the present outlook on certain aspects of magnetism, mainly those concerned with the magnetic properties of materials. An account of diamagnetism, paramagnetism and ferromagnetism is given, dealing mainly with the behavior of atoms and the interaction of atoms characteristic of each property.

The book is written primarily for those to whom the subject is not new. The author has given a reasonably systematic account of the subject, assuming as known those fundamental facts which are to be found in the usual text-books.

It is believed that the book is useful in a general survey of the subject, and as an introduction to those who wish to carry out research on the subject. It may also suggest new points of view to those whose main scientific interests lie in other directions.

RICHARD J. SHUCK

Mercury Arcs, by F. J. Teago and J. F. Gill. 107 pages. Price, $1.50.

The book is a mathematical treatment of the subject of mercury arcs used as power rectifiers and inverters. The practical side of the subject is covered briefly in the introduction and the chapter on constructional details. Throughout the book where theoretical results deviate from actual results, the deviation is noted but not treated in detail. Control, regulation, characteristics, wave form analysis, transformer ratings, and power factors are among the subjects presented. In all, the book presents a rather complete mathematical analysis of mercury arcs and will be of particular interest to the students of electrical engineering, physics and mathematics.

E. A. MECHLER

The General Principles of Quantum Theory, by G. Temple. 120 pages. 1948. Price, $1.25.

The title, "The General Principles of Quantum Theory," is an excellent one for this monograph. It deals with the basic concepts underlying the quantum theory. A brief, and of necessity intense, survey of the theory of linear operators is given, from which the general laws governing the interpretation of experimental observations in atomic (i.e., elemental) physics are developed. It is shown that the dominant fact in these laws is the uncertainty principle,

and this is expressed precisely in Heisenberg's exchange relations. From these, the equations of motion are obtained and applied to a few simple cases. The spin operators are discussed as a representation of the state of the system that is independent of any particular coordinate system. Some treatment of relativistic quantum theory is given, and the foundation for the treatment of systems of many particles is laid.

In general, the treatment is extremely concise, couched mainly in the language of linear operators. It is by no means an introductory book, but is excellent as a background for the theoretical physicist already thoroughly familiar with the workings of quantum mechanics. Although titled a fourth edition, it is substantially the same as the first, published in 1934. However, a work of this kind, dealing with the fundamental physical and mathematical concepts behind a theory, is not very dependent upon the recentness of its material, and in this case, is still a valuable book.

A. D. FRANKLIN

Hyperfine Structure in Line Spectra and Nuclear Spin, by S. Tolansky, 120 pages. 1948. Price, $1.50.

In this book Professor Tolansky has given a simple, clearly written account of the hyperfine structure arising in atomic line spectra from the perturbation of electronic energy levels by the spin magnetic moment of the nucleus. A brief summary of the special resolution problems arising in the observation of hyperfine structure is given. Multiplicity in line spectra is simply described in terms of the vector coupling models, and the effect of nuclear spin is shown to be a further multiplicity. Analysis of the hyperfine structure in terms of component intensities and intervals is discussed. A short section is given on the isotope effect and on perturbations in hyperfine structures. The last three chapters discuss some of the resulting ideas growing out of the analyses of hyperfine structure, in terms of nuclear spins, magnetic moments, and electrical quadrupole moments. Two appendices discuss the Zeeman effect and the single particle theory of nuclear spins.

The book suffers from one drawback, that of lack of recentness of its material. Large strides have been made in the field of nuclear spin investigations since the first edition was published in 1935, especially in the determination of nuclear electric quadrupole moments by means of microwave spectroscopy. This reviewer would recommend this book as an excellent introduction to the field of nuclear spins and hyperfine structure, and as a survey of the work before 1935.

A. D. FRANKLIN

X-Ray Optics, by A. J. C. Wilson, 127 pages. 1949. Price, $1.50.

This well written little book presents an easily understood discussion of the uses of the reciprocal lattice. Some of the problems treated are: the construction and properties of the reciprocal lattice; the representation of crystals in reciprocal space; the lattice's relation to diffraction photographs; the effects of crystal imperfections on X-ray photographs; and the effects of thermal motion on X-ray diffraction. The author has intentionally omitted a discussion of the use of Fourier series in the investigation of crystal structures, because of considerations of space and possible overlapping with other books in this series.

EZRA S. KRENDEL

BOOK NOTES

AN INDEX OF NOMOGRAMS, compiled and edited by Douglas Payne Adams. 174 pages, 18 × 24 cm. Cambridge, Technology Press of M.I.T. and New York, John Wiley & Sons, Inc., 1950. Price, $4.00.

This work should prove valuable in making available more than 1700 nomograms which have been published in periodicals since 1923. The term "nomogram" has been used in the popular sense of referring to alignment diagrams exclusively.

There are two parts to the work: Index A—Key Words, and Index B—Master List. The former comprises an alphabetical listing of the one or two words most naturally associated with

each of the diagrams followed by a key number referring to Index B. This latter is arranged in twenty-one broad subject divisions to facilitate scanning nomograms in a particular field. Each entry includes title, periodical citation in a compact tabular form, a listing of the variables employed in the diagram, and the name of the author. Since the names of the periodicals have been quite drastically abbreviated, it is necessary to refer constantly to the list of abbreviations, which has been placed between the two lists, necessitating considerable fumbling. It would seem preferable to have placed the list of abbreviations either at the front or back to facilitate reference.

It is the writer's opinion that it also would have been more logical to have placed Index A after Index B, which would have automatically solved the problem of location of abbreviations. Despite these possible hindrances to easy use, the *Index of Nomograms* makes available much valuable material and it is to be hoped that the compiler will keep it up to date.

THE MECHANICAL PROPERTIES OF WOOD, by Frederick F. Wangaard. 377 pages, illustrations, 15 × 22 cm. New York, John Wiley & Sons, Inc., 1950. Price, $6.00.

Based on George A. Garratt's book *Mechanical Properties of Wood* published in 1931, the present work reflects the subsequent developments in timber mechanics and timber engineering. The four parts treat: the basic mechanical properties of clear wood; factors affecting the mechanical properties of wood; working stresses for structural timber; and timber testing. Extensive tables of the properties of some 150 American woods are included. Intended primarily as a textbook for students of wood technology, the work should prove useful for all those seeking information on the properties of wood.

THE PHYSICAL CHEMISTRY OF ELECTROLYTIC SOLUTIONS, by Herbert S. Harned and Benton S. Owen. Second edition, 645 pages, diagrams, 16 × 24 cm. New York, Reinhold Publishing Corp., 1950. Price, $10.00.

New material for this second edition of a basic treatise has been incorporated in an appendix to avoid the necessity of an expensive revision of the entire text. Corrections of errors have been made throughout the text and cross references have been introduced between the tables in the main body of the book and the new appendix.

SMITH'S INTRODUCTORY COLLEGE CHEMISTRY, by William F. Ehret. Third edition, 511 pages, illustrations, 18 × 26 cm. New York, Appleton-Century-Crofts, 1950.

Many changes have been introduced in this new edition including an increased use of equations, the elimination of many outmoded illustrations and the substitution of new ones, and various modifications in the text. A significant change has been the introduction of the nomenclature recommended by the International Union of Chemistry.

FUNDAMENTALS OF ORGANIC CHEMISTRY, by James Bryant Conant and Albert Harold Blatt. 413 pages, 14 × 22 cm. New York, The Macmillan Co., 1950. Price, $4.00.

Intended primarily as a simplified version of the authors' *Chemistry of Organic Compounds*, this text has been prepared especially for those students who desire a knowledge of organic chemistry but who do not plan to become professional chemists. The authors envision the importance of biochemistry to many of the potential users of the book and they realize the importance of the organic chemical industry in the economic life of the nation today. Accordingly, the central theme of the book is twofold—"a condensation of the organic chemistry of living things and the utilization for practical ends of the products of life processes."

ENGINEERING SURVEYS: ELEMENTARY AND APPLIED, by Harry Rubey, George Edward Lommel and Marion Wesley Todd. Second edition, 722 plus 169 pages, illustrations, tables, 13 × 20 cm. New York, The Macmillan Co., 1950. Price, $5.00.

This standard textbook on engineering surveys now appears in a revised edition. The major changes occur in the chapters on land surveys, engineering astronomy and photogrammetry, each of which has been brought up-to-date, incorporating new data and developments. The lists of references given with each chapter have also been revised.

AUTHOR'S GUIDE FOR PREPARING MANUSCRIPT AND HANDLING PROOF. 80 pages, illustrations, 15 × 23 cm. New York, John Wiley & Sons, Inc., 1950. Price, $2.00.

A revision of an earlier publication entitled "The Manuscript—A Guide for Its Preparation," the present volume has been designed to enlist the author's active interest and cooperation in the preparation of his manuscript. By following certain well defined procedures, the author can contribute to the more economical production of his book, thus helping to offset the present greatly increased costs of book manufacture, especially of technical books. Thus the purpose of the book as stated in the preface is twofold: "To guide the author in the efficient preparation of his material, both manuscript and illustrations; and to inform him of the publishing procedures from the time he submits his manuscript until he has the printed book in hand, including the best and most economical methods of handling proof." This has been accomplished in a concise fashion which should prove stimulating to the prospective author. An extensive glossary provides definitions of terms which an author may encounter in the process of having his book published.

DESCRIPTIVE GEOMETRY WORKSHEETS, by E. G. Pare, R. O. Loving, and I. L. Hill. Unpaged, plates, 23 × 28 cm. New York, The Macmillan Co., 1950. Price $2.50.

A selection of problems in descriptive geometry which endeavors to emphasize the practical applications that the student may be able to make. References to five different texts are given for descriptive material. The sheets are perforated to facilitate removal.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

Effects of Varying Oxygen Tension on Mortality of X-Rayed Mice.—GEORGE LIMPEROS. The mortality of mice exposed to x-radiation was found to be reduced by thiourea (5) possibly because of its anti-thyroid activity. Blount *et al* (1) reported that desiccated thyroid increased the mortality of mice exposed to x-radiation and also increased oxygen consumption by 40 per cent. The increase in oxidative metabolism has been suggested by Smith *et al* (7) as the factor responsible for the increase in mortality of mice exposed to x-radiation at a low environmental temperature. Increasing the oxygen tension might, therefore, increase the mortality of mice exposed to x-radiation and, conversely, reducing the oxygen tension might reduce mortality. The results of preliminary experiments are reported at this time.

Male, white mice (Detwiler) weighing 18–22 g. were allowed Fox Food Blox (Allied Mills) and water *ad libitum*. The mice were irradiated in groups of 15 with 500 r given at a rate of 74 r/min. The

TABLE I.—*Effect of Increased and Decreased Oxygen Tension on the Mortality of Mice X-Rayed with 500 r.*

Treatment	No. of mice	Survived 1st week %	2nd week %	3rd week %	4th week %
Control	15	87	20	13	7
100% O_2	15	87	0	0	0
10% O_2	15	93	60	53	47
Control	15	73	40	33	20
100% O_2	15	73	13	7	0
10% O_2	15	80	73	53	47

control mice were irradiated on the same day as the mice under varied oxygen tensions. The constants of the x-ray machine were 250 K.V.P. and 15 m.a. A copper filter ½ mm. thick was used in addition to the inherent filtration of 3 mm. of aluminum. The mice were irradiated in a cylindrical, air-tight cage 21.3 cm. in diameter and 8 cm. deep, with a glass top for observing the mice. The cage had an opening on one side for the introduction of the mice and the insertion of the gas line. Another opening on the opposite side allowed for the insertion of a return line to a water-bubble valve. A 10 per cent O_2–90 per cent N_2 mixture was used for the low oxygen atmosphere and 100 per cent O_2 (99.5 per cent purity) was used for the high oxygen atmosphere. These concentrations were tolerated by the mice without any difficulty.

After flushing out the lines with the particular gas mixture to be used, the gas lines were connected to the cage containing the mice.

The gas mixture was introduced at atmospheric pressure and at a fairly rapid rate for $4\frac{1}{4}$ min. before irradiation and then continued during the entire period of irradiation ($6\frac{3}{4}$ min.). The results shown in Table I indicate that the high oxygen atmosphere increases and that the low oxygen atmosphere decreases the mortality of mice exposed to x-radiation. Of the control group irradiated under a normal oxygen atmosphere, 13 per cent survived: none survived under the high oxygen atmosphere ($p = 0.03$ approx.), and 47 per cent survived under the low oxygen atmosphere ($p \ll 0.01$). The median length of life was 11 days for the control group, 8.5 days for the increased oxygen group, and 22 days for the decreased oxygen group.

The results of these experiments indicate that changing the oxygen tension of mice alters their susceptibility to total-body x-radiation. Hydroxyl free radicals generated from the medium were shown to be partly responsible for the action of x-rays on aqueous solutions (**2**, **3**, **6**). According to Krenz (**4**), in the presence of oxygen, the hydrogen atoms (H) may react to form hydroperoxide radicals (HO_2) and eventually hydrogen peroxide.

$$H + O_2 \longrightarrow HO_2 \qquad I$$
$$HO_2 + H \longrightarrow H_2O_2 \qquad II$$

Thus, the possible oxidation reactions due to the hydroxyl radicals can be augmented by the formation of H_2O_2 and HO_2. As pointed out by Krenz (**4**), reactions (I) and (II) can compete with the back reaction of H atoms and OH radicals to form water (III).

$$H + OH \longrightarrow H_2O \qquad III$$

This competition allows the OH radicals to escape the "cage" of surrounding water molecules and thereby their activity is increased.

It appears that oxygen tension plays an important part in the biological effects of x-radiation. The production of H_2O_2 and HO_2 and the "release" of the OH radicals from the back reaction shown in equation (III) may account for the increased mortality of mice x-rayed under a higher oxygen atmosphere. The low oxygen atmosphere exerts a protective effect possibly because it decreases the concentration of OH and HO_2 radicals and of H_2O_2.

REFERENCES

(1) H. C. BLOUNT, JR. AND W. W. SMITH, *Science*, **109**, 83 (1949).
(2) E. COLLINSON, F. S. DAINTON AND B. HOLMES, *Nature*, **165**, 267 (1950).
(3) F. S. DAINTON, *Nature*, **160**, 268 (1947).
(4) F. H. KRENZ, in "Proceedings of the Conference on Nuclear Chemistry," Ottawa, The Chemical Institute of Canada, 1947.
(5) G. LIMPEROS AND W. A. MOSHER, *Science*, in press.
(6) G. LIMPEROS AND W. A. MOSHER, *Am. J. Roentgenol. Radium Therapy*, in press.
(7) W. W. SMITH, J. HIGHMAN, J. R. MITCHELL AND H. C. BLOUNT, JR., *Proc. Soc. Exp. Biol. Med.*, **71**, 498 (1949).

CURRENT TOPICS

Computers That Correct Their Own Errors.—A means for endowing modern computers, or "thinking machines," with a whole new faculty—the ability not only to detect their own mistakes but actually to correct them—has been developed at Bell Telephone Laboratories, research and development organization of the Bell System.

The discovery is regarded as one of the most important and fundamental advances in computer techniques since the development of these powerful scientific tools.

It is also expected to be of significance in the general communication field, where transmission is on a code basis.

The best that present computers can do is to recognize when they have made a mistake, and not all computers can do even this. Errors usually occur when a vacuum tube burns out or a switch fails to open or close properly. When this happens, some of the modern calculators will retrace their steps to the last check-point and try again. If the same mistake recurs, they will stop and flash a light, ring a bell or otherwise summon a repairman.

The Bell Laboratories improvement makes it possible for the computer not only to recognize that it has made a mistake and record that fact, including the approximate location, but to correct the error and proceed to the right answer. This is expected to be very valuable since it is common practice for engineers to give a problem to a computer and leave it to work at it, overnight or even over a weekend, without human supervision.

The basic concepts underlying the new technique are the direct result of pure mathematical research carried out by Dr. R. W. Hamming, Bell Laboratories mathematician. Apparatus incorporating the mathematical discovery has been constructed under the direction of B. D. Holbrook, Bell Laboratories switching research engineer.

This apparatus has not as yet been embodied in a complete computer but it represents a working application of the mathematical principles devised by Dr. Hamming. Similar apparatus could readily be fitted into future calculating machines.

The laboratory model already constructed is designed to catch and correct one mistake and to catch—but not correct—two simultaneous mistakes. In the very unlikely event that two simultaneous mistakes should occur the apparatus will so indicate and will summon help.

Dr. Hamming's mathematical theories would permit a computer to catch and correct as many errors as the designer wished. Since the chance of two breakdowns occurring at once is extremely small, perhaps only one in a million million relay operations, for example, it is not believed economically feasible to add apparatus for this purpose.

The new method can be applied to any type of digital computer, either the electronic types, such as ENIAC, which operate with vacuum tubes, or the relay type, originally developed by Bell Telephone Laboratories. This latter type of calculator uses electrical switches, or relays, similar to those used to operate the familiar dial telephone system.

A general discussion of the theory is contained in the *Bell System Technical Journal* for April 1950 and the *Bell Laboratories Record* for May 1950.

Phototransistor.—An entirely new type of "electric eye"—much smaller and sturdier than present photo-electric cells and possibly cheaper—has been invented at Bell Telephone Laboratories.

During the past quarter-century, electric eyes have found widespread use in electronics because of their ability to control electric currents by the action of light. To the layman, one type is perhaps best known for automatically opening and closing doors, but such devices have many other important uses—in television, sound motion pictures, wirephotos, and still many more in industry.

One of the major advantages of the new electric eye is that it delivers very high power for a photo-electric device—in some cases enough to operate a switch directly without the preliminary amplification usually required.

The new electric eye stemmed from work at Bell Laboratories on the recently-announced Transistor, an amazingly simple device capable of performing most of the functions of an ordinary vacuum tube.

Appropriately, the new device has been named the Phototransistor. The whole apparatus is housed in a tiny cylinder about as big as a .22 calibre rifle cartridge. Like the Transistor, it has no vacuum, no glass envelope, no grid, plate or hot cathode. Both the Transistor and the Phototransistor are the result of fundamental research into the electrical properties of solids which has been in progress at Bell Telephone Laboratories for some time.

Although the Phototransistor is still in the experimental stage, Laboratories scientists and engineers expect that, after the necessary development, it may have far-reaching significance in electronics and electrical communication.

Just as the Transistor is not expected to supplant vacuum tubes, but rather to supplement them, so the Phototransistor is not expected to displace existing photo-electric cells. Because of their small size and expected long life, however, together with economies that might reasonably result from mass-production, Phototransistors should find many applications where it is not now practical to use present-day photoelectric devices.

Consideration is already being given, for example, to using them in a machine under development for toll dialing, a plan whereby a telephone operator directly dials a telephone in a distant city.

The heart of the parent device, the amplifying Transistor, is a tiny chip of germanium, a semi-conductor material, against one side of which the points of two hair-thin wires are pressed, hardly two-thousandths of an inch apart. The flow of very small electrical currents in one of these wires (the emitter) controls the flow of currents in the other wire (the collector) in such a way as to give signal amplification.

The Phototransistor is similar in operation to the amplifying Transistor, but it is controlled by light rather than by the electric current of the emitter. It also uses a piece of germanium but only a single collector wire. The tip of this wire rests in a small dimple ground into one side of the germanium disk. At this point the germanium disk is only three thousandths of an inch thick.

Light focused on the opposite, undimpled side of the disk can control the flow of current in the wire, thus making a control device similar in function to a photo-electric cell.

The Phototransistor has a high power output for a photo-electric device and gives good response to a rapidly fluctuating light source. It is particularly

sensitive to the wavelengths of light given off by ordinary incandescent light bulbs, and is well suited to operate with these easily available sources with good fidelity. Another virtue is the device's low impedance.

Rollosprayer.—Chemical control of weeds in turf has been greatly facilitated by the invention of the Rollosprayer. Invented by Walter S. Lapp, of Lansdale, Pa., the Rollosprayer was originally designed to spray weedkillers on lawns and other turfed areas. It has also been found to be useful in applying insecticides, fungicides and soluble fertilizers on lawns, estates, golf greens, bowling greens, parks, athletic fields and cemeteries. Industrially it is suitable for spraying dust-laying solutions, sanitizing agents and clear water to the floors of factories, shops, warehouses, stores and schools.

The machine is simple in construction. The traction of the wheels supplies power to a small impeller pump which creates sufficient pressure to produce a flat fan-shaped spray 5 ft. wide as the machine is pushed along. The Rollosprayer is especially adapted for areas too large for a hand sprayer and too small for a power sprayer. It is in general comparable to the hand lawnmower in range of usefulness.

Pee-Wee Radio Tube May Reduce Size of Electronic Equipment (*The Martin Star*, March, 1950).—A "Tom Thumb" synthetic radio tube, about the size of a match head, may be the Air Forces' answer to the question of how to reduce the weight and size of its airborne electronic equipment. Called a "fieldistor," the sub-miniature tube is now in the early stage of development at the Air Materiel Command's Components and Systems Laboratory at Wright-Patterson Air Force Base, Dayton, Ohio.

Being only 1/90th the size of the present-day tube, the "fieldistor" offers tremendous advantages from a weight and space standpoint . . . an all important factor in aircraft equipment. In appearance, it resembles the end of an eye dropper. Ten of them could be carried in an ordinary thimble.

Possible adoption of the small tube to civilian usage is seen in such items as radio, television, hearing aids, fire and burglar alarms, thermostats, etc.

"But don't expect to see any of the new devices in civilian items for some time yet," says Colonel Duggar, Components and Systems Lab chief. "The 'fieldistor' is still in the process of development." For one thing, the tube is still a bit too noisy. About 250 have been made to date, by hand, and the cost is too high for the average pocketbook.

A small electronic "brain" which can analyze nervous systems of living bodies has been developed for the Office of Naval Research by the University of Pennsylvania. The computer, which also can make blood counts, was demonstrated for the first time on April 13 at the Bellevue Hotel, Philadelphia.

Power and heat are provided for vessels with boilers down for repairs at the San Francisco Port of Embarkation by an 88-foot power-supply barge, used by the Army Transportation Corps. One big saving results from the practicability of keeping crews aboard while repairs are under way. The barge has two Diesel-driven generators and a 100-hp. vertical tubular boiler.

Development of a hollow steel, 19-ft. flash-welded propeller suitable for quantity production is under way at the Air Materiel Command, Dayton, Ohio. The Air Force at the same time is attempting to improve production techniques of these propeller blades. One of the type has completed a run-out at 21,000 psi. on a resonant fatigue machine. Engine tests are due soon.

Electronic engine analyzers, used on scheduled airlines as in-flight trouble-shooters, are being purchased by the Air Force for use in boosting cruised-controlled range of big bombers, such as the B-50, which flew around the world last year with in-flight refueling. Expected to be of value on combat missions, the analyzers detect and locate detonation the instant it occurs in a cylinder. By leaning the fuel mixture just to the point that detonation starts, more range can be gotten from available supply.

INDEX TO VOLUME 249

January to June, 1950

References with (N) are Notes from the National Bureau of Standards and references with (C) are Current Topics

Adhesion. Nature of adhesion, 410(N)

Adiabatic flow. Application of near-equilibrium criteria during adiabatic flow to representative propellant systems (Penner), 441

Aeronautics. Atomic energy for aircraft, 138(C)

Blood transfusions raise man's high-altitude ceiling, 188(C)

Electronic engine analyzers, 518(C)

Fatigue limit of chromium-plated steels for aircraft, 155(N)

Aggregates. Properties of lightweight aggregate concretes, 410(N)

Anticorrosion liquid may be pumped moisture-free, 132(C)

Approximation of functions. A note on the solution of certain approximation problems in network synthesis (Fano), 189

Atomic energy for aircraft, 138(C)

Atomic physics. The omegatron, 491(N)

Baseboard heater. Performance of a baseboard heater, 240(N)

Batt, William L.: Vision knows no boundaries, 347

Bending of plates. Trigonometric series applied to the bending of long rectangular plates to a cylindrical surface (Fo-Van Chang), 279

Biochemistry. The influence of the temperature and the period of keeping upon the biochemical changes in the common fowl *gallus domesticus* (Hepburn), 393, 475

Book reviews:

Abbott, Ira H. and Albert E. von Doenhoff: Theory of wing sections, 254

Adams, Douglas Payne, editor: An index of nomograms, 510

Annual reports on the progress of chemistry for 1948, 170

Arley, Niels and K. Rander Buch: Introduction to the theory of probability and statistics, 339

Author's guide for preparing manuscript and handling proof, 512

Babor, Joseph A. and Alexander Lehrman: Introductory college chemistry, 260

Barre, H. J. and L. L. Sammet: Farm structures, 425

Beranek, Leo L.: Acoustic measurements, 101

Bergmann, Peter Gabriel: Basic theories of physics; mechanics and electrodynamics, 255

Berkeley, Edmund Callis: Giant brains or machines that think, 252

Booth, Harold S. and Donald R. Martin: Boron trifluoride and its derivatives, 170

Born, M. and H. S. Green: A general kinetic theory of liquids, 338

Bragg, Sir Lawrence: The crystalline state, 102

Brodbeck, Emil E.: Handbook of basic motion-picture techniques, 426

Butler, Sir Edwin J. and S. G. Jones: Plant pathology, 426

Chapanis, Alphonse, Wendell R. Garner and Clifford T. Morgan: Applied experimental psychology, 165

Chatfield, C. H., C. Fayette Taylor and Shatswell Ober: The airplane and its engine, 254

Childs, W. H. J.: Physical constants, 507

Cohen, I. Bernard: Some early tools of American science, 423

Conant, James Bryant and Albert Harold Blatt: Fundamentals of organic chemistry, 511

Copenhaver, John W. and Maurice H. Bigelow: Acetylene and carbon monoxide chemistry, 166

Creager, William P. and Joel D. Justin: Hydroelectric handbook, 425

Dubos, Rene: Louis Pasteur; free lance of science, 334

Duncan, Winifred: Webs in the wind, 100
Dusinberre, G. M.: Numerical analysis of heat flow, 256
Dwinnell, James H.: Principles of aerodynamics, 167
Eastman, Austin V.: Fundamentals of vacuum tubes, 102
Ehret, William F.: Smith's introductory college chemistry, 511
Einstein, Albert: The meaning of relativity, 334
Einstein, Albert: Out of my later years, 502
Electronic engineering master index for 1947–1948, 340
Elmore, W. C. and Matthew L. Sands: Electronics: experimental techniques, 99
Engineering structures, 506
Erickson, Robert L.: Fundamental algebra with practical applications, 104
Farrington, S. Kip: Railroads of today, 168
Francis, V. J.: Fundamentals of discharge tube circuits, 507
Franklin, Philip: Fourier methods, 258
Fraprie, Frank R. and Franklin I. Jordan, editors: The American annual of photography, 1950, 169
Fritsch, Volker: Grundzuege der angewandten geoelektrik, 169
Guthrie, A. and R. K. Wakerling, editors: The characteristics of electrical discharges in magnetic fields, 259
Hamilton, C. S., editor: Organic syntheses, Vol. 29, 337
Harned, Herbert S. and Benton S. Owen: The physical chemistry of electrolytic solutions, 511
Hayden, Arthur G. and Maurice Barron: The rigid-frame bridge, 425
Hess, Victor F. and Jakob Eugster: Cosmic radiation and its biological effects, 335
Higdon, Archie and William B. Stiles: Engineering mechanics, 342
Hill, W. Ryland: Electronics in engineering, 257
Hine, Charles R.: Machine tools for engineers, 338
Jackson, L. C.: Low temperature physics, 507
Jaeger, J. C.: An introduction to the Laplace transformation, 508
Jones, Charles R.: Facsimile, 255
Kaufman, Milton: Radio operator's license Q and A manual, 342
Keynes, Geoffrey: The personality of William Harvey, 422
Knudsen, V. O. and C. M. Harris: Acoustical designing in architecture, 504
Langmuir, Irving: Phenomena, atoms and molecules, 422
Le Corbeiller, P.: Matrix analysis of electric networks, 340
Lee, Oliver Justin: Measuring the universe, 336
Leet, I. Don: Earth waves, 340
Le Fevre, R. J. W.: Dipole moments, 508
Leverenz, Humboldt W.: An introduction to luminescence of solids, 506
Lewis, Walter W.: The protection of transmission systems against lightning, 337
Lexique technique, Français-Anglais et Anglais-Français concernant le materiel de travaux publics, 342
Lichnerowicz, A.: Eléments de calcul tensoriel, 426
Linksz, Arthur: Physiology of the eye—Vol. I—Optics, 424
Lucas, Howard J. and David Pressman: Principles and practice in organic chemistry, 101
Mann, W. B.: The cyclotron, 508
Marek, Clarence T.: Fundamentals in the production and design of castings, 505
Martin, Thomas: Faraday's discovery of electromagnetic induction, 424
McVittie, G. C.: Cosmological theory, 508
Mees, C. E. Kenneth and John A. Leermakers: The organization of industrial scientific research, 503
Methuen's monographs on physical subjects, 507
Milne-Thomson, L. M.: Theoretical hydrodynamics, 502
Obert, Edward F.: Elements of thermodynamics and heat transfer, 166
Offenhauser, William H., Jr.: 16-mm. sound motion pictures, 261
Paré, E. G., R. O. Loving and I. L. Hill: Descriptive geometry worksheets, 512
Pender, Harold and William Del Mar, editors: Electrical engineers' handbook, volume 1, electric power, 104
Perkins, Courtland D. and Robert E. Hage: Airplane performance, stability and control, 503
Poorman, Alfred P.: Applied mechanics, 103

PSA Journal 1950 Annual, 426
Puri, A. N.: Soils, their physics and chemistry, 342
Ratcliffe, J. A.: The physical principles of wireless, 509
Riegel, Emil R.: Industrial chemistry, an elementary treatise for the student and general reader, 168
Robb, Louis A.: Engineers' dictionary: Spanish-English and English-Spanish, 258
Rubey, Harry, George Edward Lommel and Marion Wesley Todd: Engineering surveys, 511
Rucker, Leslie C.: The business helper, 170
Ruiter, Jacob H., Jr.: Modern oscilloscopes and their uses, 103
Sadler, D. H.: Astronomy and navigation, 260
Schilpp, Paul Arthur, editor: Albert Einstein: philosopher and scientist, 252
Schlaifer, Robert and S. D. Heron: Development of aircraft engines and aviation fuels, 339
Schlick, Moritz: The philosophy of nature, 99
Severns, William H. and Julian R. Fellows: Heating, ventilating and air-conditioning fundamentals, 260
Shoop, Charles F. and George L. Tuve: Mechanical engineering practice, 104
Spratt, H. Philip: Outline history of transatlantic steam navigation, 505
Stoner, E. C.: Magnetism, 509
Sullivan, William H.: Trilinear chart of nuclear species, 253
Teago, F. J. and J. F. Gill: Mercury arcs, 509
Temple, G.: The general principles of quantum theory, 509
Third symposium on combustion flame and explosion phenomena, 255
Tolansky, S.: Hyperfine structure in line spectra and nuclear spin, 510
von Loesecke, Harry W.: Outlines of food technology, 169
Walton, H. F.: Inorganic preparations, 104
Wangaard, Frederick F.: The mechanical properties of wood, 511
Wiener, Norbert: The extrapolation, interpolation and smoothing of stationary time series with engineering applications, 259
Wilson, A. J. C.: X-ray optics, 510
Woldman, Norman E.: Materials engineering of metal products, 341
Year book of the Textile Institute No. 2, 1949–50, 261
Zepler, E. E.: The technique of radio design, 104
Zwikker, C. and C. W. Kosten: Sound absorbing materials, 257
Boyajian, A.: Origin and meaning of circular and hyperbolic functions in electrical engineering, 117
Bridges. Perforated cover plates for steel columns, 239(N)
Broadbanding. Theoretical limitations on the broadband matching of arbitrary impedances (Fano), 57, 139
Buttons, buckles and fasteners can now be dry-cleaned and laundered, 434(C)
Cavendish, Henry, electrician (Susskind), 181
Cement gun, 262(C)
Census. Stand up and be counted, 431(C)
Ceramics. High-strength ceramics for high-temperature use, 411(N)
Chambers, Dudley E.: Some aspects of the function, organization and operation of industrial research and development laboratories, 287
Chart-making. A new zenith camera for use in aeronautical chart-making, 188(C)
Chromium. Fatigue limit of chromium-plated steels for aircraft, 155(N)
Circular functions. Origin and meaning of circular and hyperbolic functions in electrical engineering (Boyajian), 117
Clamer, G. H.: Research from the standpoint of the smaller business enterprise, 367
Clay improvement process, 172(C)
Cleaning. Shot blast cleaning machine, 345(C)
Cold storage. The influence of the temperature and the period of keeping upon the biochemical changes in the common fowl *gallus domesticus* (Hepburn), 393, 475
Collapsible 26-ft. dory with a 3000-lb. cargo capacity, 132(C)
Color television. New industrial television system, 358(C)
Communications and electronics—the most essential tools of joint command (Stone), 109
Computers that correct their own errors, 515(C)

Concrete. Properties of lightweight aggregate concretes, 410(N)
New building construction technique, 408(C)
Construction. Cement gun, 262(C)
Contax-S Zeiss-Ikon camera, 263(C)
Cosmic rays. Concerning meson produced secondary electrons emerging from thin foils (Hereford), 449
Cosmic rays explode magnetic sun theory, 105(C)
Cosmic rays. Fluctuations in proportional counters (Swann), 133
Cotton. Mechanization of cotton moves ahead, 56(C)
Coulson, Thomas: The Franklin Institute from 1824 to 1949, 1
Cranes. A saving of nearly 900 per cent in man-hours, 132(C)
Crystals. Very thin crystal oscillator plates, 237(N)
Curve plotting. X-Y recorder, 346(C)
Cylindrical bending of plates. Trigonometric series applied to the bending of long rectangular plates to a cylindrical surface (Fo-Van Chang), 279

Demonstration magnetic amplifier for educational and laboratory use, 345(C)
Diffraction by circular disks. The oblate spheroidal wave functions (Leitner and Spence), 299
Drexel Institute. Founder's medal of Drexel Institute, 107(C)
Dry cleaning. Buttons, buckles and fasteners can now be dry-cleaned and laundered, 434(C)
Dye-tube spindle eliminates dye trapping, 56(C)

Edible covering on food bars in survival rations, 278(C)
Elasticity. A note on the notch effect of metals (Minamiozi and Okubo), 49
Electricity. Grid contact potential and associated grid currents (Michaelson), 455
Electronic brains "shrinking," 433(C)
Electronic engine analyzers, 518(C)
Electronics. Communications and electronics—the most essential tools of joint command (Stone), 109
Miniature atomic "explosion" in billionth of a second can be observed by use of new RCA oscilloscope, 108(C)
Music lessons by electronics, 392(C)
Phototransistor, 516(C)
Rugged electron tubes, 85(N)
A small electronic "brain," 517(C)
Stand up and be counted, 431(C)
Electrons. Concerning meson produced secondary electrons emerging from thin foils (Hereford), 449
Elongation. Photo-grid technique for measuring sheet-metal elongation, 238(N)
Emulsions. "Developable" and developed silver halide grains (Silberstein), 207
Europe revisited (Odgers), 265
Explosives. New process for stabilizing guncotton aids national defense, 171(C)

Fano, R. M.: A note on the solution of certain approximation problems in network synthesis, 189
Theoretical limitations on the broadband matching of arbitrary impedances, 57, 139
Farming. Push-button farm boy, 262(C)
Fatigue limit of chromium-plated steels for aircraft, 155(N)
Fatigue testing. A note on the notch effect of metals (Minamiozi and Okubo), 49
Fiber-glass. Tough, light, noncorrosive fiberglass pipe, 56(C)
Fire detection. Flame detector, 346(C)
A photoelectric fire-detection device for aircraft use, 132(C)
Fire-retardant coatings for aircraft, 409(N)
Flame detector, 346(C)
Fluctuations in proportional counters (Swann), 133
Foote Mineral Company Laboratories, 278(C)
Fo-Van Chang: Trigonometric series applied to the bending of long rectangular plates to a cylindrical surface, 279
Fracture. The part of octahedral theory in the study of the plasticity of metals (Roop), 223
The Franklin Institute from 1824 to 1949 (Coulson), 1
The Franklin Institute:
Bartol Research Foundation, 95
Biochemical Research Foundation Notes:
Ely, J. O. and M. H. Ross: *Abstract of* Lack of depolymerase effect on desoxyribonucleic acid in living cells, 97
Ely, J. O. and M. H. Ross: *Abstract of* Nucleic acid and the Feulgen reaction, 97

Krecji, Laura E., Lucile Sweeny and John Hambleton: *Abstract of* A polysaccharide related to the blood group substances and its reaction with borate. II. A study of sedimentation and viscosity, 164

Krejci, Laura E., Lucile Sweeny and Robert K. Jennings: *Abstract of* Electrophoretic and serological properties of the non-dialyzable growth products of *Vibrio cholerae*, 343

Krejci, Laura E., Lucile Sweeny and Charles A. Zittle: *Abstract of* A polysaccharide related to the blood group substances and its reaction with borate. I. A study by electrophoresis, 164

Leitch, James L., Douglas M. Gay and George A. Neville: *Abstract of* Effects of repeated low doses of neutrons on the estrous cycle of the white rat, 97

Limperos, George: Effects of varying oxygen tension on mortality of x-rayed mice, 513

Reinhart, Francis E.: The preparation of several substituted phenyl 2-pyridyl sulfides and sulfones, 248

Reinhart, Francis E.: The preparation of some 6-substituted nicotinic acids, 427

Ross, M. H. and J. O. Ely: *Abstract of* Alkaline phosphatase activity and desoxyribonucleic acid, 343

Ross, M. H. and J. O. Ely: *Abstract of* Neutron effects on alkaline phosphatase of rat intestine, 344

Ross, M. H. and J. O. Ely: *Abstract of* Neutron and Roentgen-ray effects on protein content of rat intestine, 344

Smith, Louis DeSpain, and Mary Virginia Gardner: *Abstract of* The occurrence of vegetative cells of *Clostridium perfringens* in soil, 164

Budd, Edward G., Lecture: Vision knows no boundaries (Batt), 347

By laws, 174

Committee on Science and the Arts: Abstract of proceedings, March 8, 1950, 325; April 12, 1950, 413; May 10, 1950, 496

Founder's medal of Drexel Institute, 107(C)

The Franklin Institute Laboratories for Research and Development, 91, 160, 243, 328, 419, 496

Journal of The Franklin Institute, 92, 159, 241, 327, 417, 495

Library, 93, 162, 245, 332, 417, 499

Membership, 89, 159, 247, 327, 414, 498

Museum, 90, 158, 242, 326, 416, 501

Stated meetings: Minutes, December 21, 1949, 88; January 18, 1950, 157; February 17, 1950, 241; March 15, 1950, 325; April 19, 1950, 413; May 17, 1950, 495

Frequency stabilization. Servo theory applied to frequency stabilization with spectral lines (Hershberger and Norton), 359

Frozen food. The influence of the temperature and the period of keeping upon the biochemical changes in the common fowl *gallus domesticus* (Hepburn), 393, 475

Fulton. Robert Fulton's first steamboat (Spratt), 435

Gloss. Permanent gloss standards, 156(N)

Glycerine, 490(C)

Grain size. "Developable" and developed silver halide grains (Silberstein), 207

Grease solvents may be easily reclaimed, 408(C)

Grid contact potential and associated grid currents (Michaelson), 455

Guncotton. New process for stabilizing guncotton aids national defense, 171(C)

Hardening. Continuous R-F induction selective hardening equipment, 172(C)

Heater compensation improves stabilized power supplies, 86(N)

Heaters. Performance of a baseboard heater, 240(N)

Hepburn, Joseph Samuel: The influence of the temperature and the period of keeping upon the biochemical changes in the common fowl *gallus domesticus*, 393, 475

Hereford, Frank L.: Concerning meson produced secondary electrons emerging from thin foils, 449

Hershberger, W. D. and L. E. Norton: Servo theory applied to frequency stabilization with spectral lines, 359

High altitude. Blood transfusions raise man's high-altitude ceiling, 188(C)

History. The Franklin Institute from 1824 to 1949 (Coulson), 1

Henry Cavendish, electrician (Susskind), 181

Robert Fulton's first steamboat (Spratt), 435
Humphreys, William Jackson. Loss of an associate editor, 98(C)
Hyperbolic functions. Origin and meaning of circular and hyperbolic functions in electrical engineering (Boyajian), 117

Industrial laboratories. Foote Mineral Company Laboratories, 278(C)
Some aspects of the function, organization and operation of industrial research and development laboratories (Chambers), 287
Industrial research. Research from the standpoint of the smaller business enterprise (Clamer), 367
In-flight refueling system, 106(C)
Infrared rays. Polarizer for infrared rays, 84(C)

Leica Tandem mount for stereo and color-monochrome duplication, 107(C)
Leitner, A. and R. D. Spence: The oblate spheroidal wave functions, 299
Linoleum. Worn out, cemented linoleum, 474(C)

Magnetic amplifier. Demonstration magnetic amplifier for educational and laboratory use, 345(C)
Magnetic sun theory. Cosmic rays explode magnetic sun theory, 105(C)
Management. Research from the standpoint of the smaller business enterprise (Clamer), 367
Some aspects of the function, organization and operation of industrial research and development laboratories (Chambers), 287
Masonry. Experimental stone masonry wall, 86(N)
Matching. Theoretical limitations on the broadband matching of arbitrary impedances (Fano), 57, 139
Mechanization of cotton moves ahead, 56(C)
Mica. Synthetic mica, 323(N)
Michaelson, Herbert B.: Grid contact potential and associated grid currents, 455
Microfilm service, 264(C)
Minamiozi, K. and H. Okubo: A note on the notch effect of metals, 49
Monel. New type spark-plug gives better service, 490(C)
Polarized light shows nature of plastic deformation in Monel metal, 493(N)
Music-composing machine, 132(C)
Music lessons by electronics, 392(C)

Naval stores. New naval stores product, 474(C)
Navigation aids. A new zenith camera for use in aeronautical chart-making, 188(C)
Necrology. Loss of an associate editor, 98(C)
Network synthesis. A note on the solution of certain approximation problems in network synthesis (Fano), 189
Theoretical limitations on the broadband matching of arbitrary impedances (Fano), 57, 139
Norton, L. E. and W. D. Hershberger: Servo theory applied to frequency stabilization with spectral lines, 359
Notch effect. A note on the notch effect of metals (Minamiozi and Okubo), 49
Nuclear energy. Propulsion of aircraft by nuclear energy, 116(C)
Nuclear physics. The omegatron, 491(N)

Oblate spheroidal wave functions, The (Leitner and Spence), 299
Octahedral theory. The part of octahedral theory in the study of the plasticity of metals (Roop), 223
Odgers, Merle M.: Europe revisited, 265
Okubo, H. and K. Minamiozi: A note on the notch effect of metals, 49
Omegatron, 491(N)
Oscillator plates. Very thin crystal oscillator plates, 237(N)
Oscilloscope. Miniature atomic "explosion" in billionth of a second can be observed by use of new RCA oscilloscope, 108(C)
Ozone. Total ozone related to troposphere temperatures, 237(N)

Penner, S. S.: Application of near-equilibrium criteria during adiabatic flow to representative propellant systems, 441
Perforated cover plates for steel columns, 239(N)
Permanent gloss standards, 156(N)
Phosphorus removal from sewage, 322(C)
Photography. Contax-S Zeiss-Ikon camera, 263(C)
"Developable" and developed silver halide grains (Silberstein), 207

Leica Tandem mount for stereo and color–monochrome duplication, 107(C)
Photo-grid technique for measuring sheet-metal elongation, 238(N)
Photometer. Plastic photometer, 490(C)
Phototransistor, 516(C)
Pipe. Tough, light, noncorrosive fiber-glass pipe, 56(C)
Plastic deformation. Polarized light shows nature of plastic deformation in Monel metal, 493(N)
Plastic flow. The part of octahedral theory in the study of the plasticity of metals (Roop), 223
Plastic photometer, 490(C)
Polarized light shows nature of plastic deformation in Monel metal, 493(N)
Polarizer for infrared rays, 84(C)
Poultry. The influence of the temperature and the period of keeping upon the biochemical changes in the common fowl *gallus domesticus* (Hepburn), 393, 475
Power and heat, 517(C)
Power. Heater compensation improves stabilized power supplies, 86(N)
Propellant systems. Application of near-equilibrium criteria during adiabatic flow to representative propellant systems (Penner), 441
Propellers. Development of a hollow steel, 19-ft. flash-welded propeller, 518(C)
Proportional counters. Fluctuations in proportional counters (Swann), 133
Protective coatings. Fire-retardant coatings for aircraft, 409(N)
Push-button farm boy, 262(C)

Radar. Baltimore installs harbor radar, 173(C)
A "flying laboratory" to test early-warning radar equipment, 116(C)
Radio. Pee-wee radio tube may reduce size of electronic equipment, 517(C)
"Starved" radio tubes, 433(C)
The world's most powerful radio station, 106(C)
Refueling. An in-flight refueling system, 106(C)
Reproduction methods. Accurate photocopies of line drawings to scale, 173(C)
Research from the standpoint of the smaller business enterprise (Clamer), 367
Research laboratories. Some aspects of the function, organization and operation of industrial research and development laboratories (Chambers), 287
Rockets. Portions of the rocket which reached a 250-mile altitude, 358(C)
Rollosprayer, 517(C)
Roop, Wendell P.: The part of octahedral theory in the study of the plasticity of metals, 223

Safety engineering. A photoelectric fire-detection device for aircraft use, 132(C)
Scale removal. A new chemical method for removing salt-deposit scale, 278(C)
Science service. A new science service for professionals and laymen, 172(C)
Servo theory applied to frequency stabilization with spectral lines (Hershberger and Norton), 359
Sewage. Phosphorus removal from sewage, 322(C)
Shelving. Heavy duty shelving, 84(C)
Ship repair. Power and heat, 517(C)
Shot blast cleaning machine, 345(C)
Silberstein, Ludwik: "Developable" and developed silver halide grains, 207
Simulated service testing. A testing platform which simulates shipboard motion, 188(C)
Soda ash. Clay improvement process, 172(C)
Spark-plugs. New type spark-plug gives better service, 490(C)
Spence, R. D. and A. Leitner: The oblate spheroidal wave functions, 299
Spheroidal wave functions. The oblate spheroidal wave functions (Leitner and Spence), 299
Spratt, H. Philip: Robert Fulton's first steamboat, 435
Statistical machines. Stand up and be counted, 431(C)
Stone, Earl E.: Communications and electronics—the most essential tools of joint command, 109
Susskind, Charles: Henry Cavendish, electrician, 181
Swann, W. F. G.: Fluctuations in proportional counters, 133
Synthetic mica, 323(N)
Synthetic rubber produced from turpentine, 206(C)

Technical documents. A central clearing house for technical documents, 474(C)

Television. New industrial television system, 358(C)
Tension meter. New tension meter twice as sensitive as old one, 116(C)
Time standards. Servo theory applied to frequency stabilization with spectral lines (Hershberger and Norton), 359
Triaxiality. The part of octahedral theory in the study of the plasticity of metals (Roop), 223
Trigonometric series applied to the bending of long rectangular plates to a cylindrical surface (Fo-Van Chang), 279
Troposphere. Total ozone related to troposphere temperatures, 237(N)
Tubes. Pee-wee radio tube may reduce size of electronic equipment, 517(C)
Rugged electron tubes, 85(N)
"Starved" radio tubes, 433(C)
Turpentine. Synthetic rubber produced from turpentine, 206(C)
Typewriter ribbons, 322(C)
Vectors. Origin and meaning of circular and hyperbolic functions in electrical engineering (Boyajian), 117
Vision knows no boundaries (Batt), 347
Visual education. New industrial television system, 358(C)

Wave functions. The oblate spheroidal wave functions (Leitner and Spence), 299
Weathering. Experimental stone masonry wall, 86(N)
Weed killing. Rollosprayer, 517(C)

Xerography. Large savings in the cost of reproducing engineering drawings, 434(C)
X-Y recorder, 346(C)